

New Scientist

WEEKLY October 10-16, 2015

SEVENTH SENSE
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gives you real-life ESP

THEY SQUEAK HIM HERE
First practical invisibility
cloak conceals a mouse

FALSE MEMORY
The creeping return of a
misremembered past

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What we know
What we don't
And what comes next

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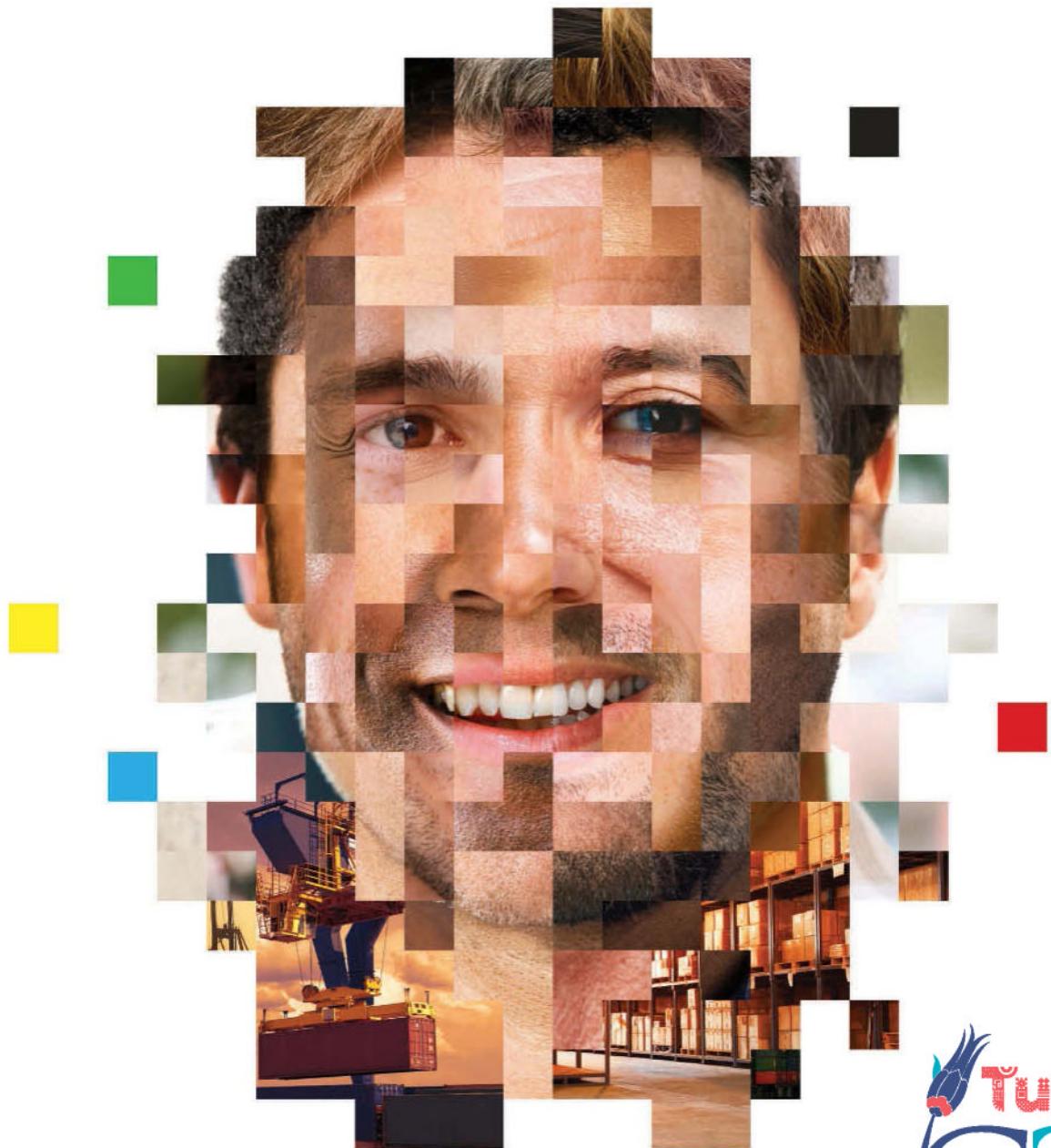


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Bad memories

We can't let a discredited psychotherapy return to wreck lives

AS THE scale of historical sexual abuse perpetrated by British celebrities and politicians becomes clearer, another scandal may be brewing. Recovered-memory therapy – claimed to be able to draw out suppressed memories of childhood trauma – is in danger of rearing its ugly head and undoing much of the progress that has been made towards transparency and closure (see page 8).

There is no specific allegation that any new claim of abuse has been precipitated by memories regained as a result of this therapy. But memory researchers are concerned. A surprising number of practitioners in the UK still use recovered-memory therapy, and as more people come forward with claims of historical abuse, there is a danger that people will become victims of a different kind.

That this is even a possibility is scandalous. Even in its heyday a few decades ago, recovered-memory therapy was built on shaky scientific ground. It has now been almost completely discredited as a therapeutic tool.

Much of the blame has to be laid at the door of psychotherapy, a broad term for a variety of techniques for resolving personal and psychological problems.

Many of these techniques are evidence-based. Many others are not; recovered memories are among the least well supported.

Scientists in the field rightly point to the "satanic panic" of the 1980s and 1990s as a warning. Dozens of children made allegations of satanic abuse, often under pressure by well-meaning social workers and therapists. Some cases were also "revealed"

Recovery of suppressed memories has been almost completely discredited as a therapeutic tool

by recovered-memory therapy. The whole thing turned out to be a collective delusion.

Part of the problem is regulation. Rules vary between countries, but in the UK, psychotherapy is regulated quite loosely. The government did consider mandatory registration for practitioners, but in 2012 decided to let the profession regulate itself. Voluntary regulation is better than none, but when people are allowed to mark their own homework it rarely leads to the most rigorous regime.

One result is a competitive psychotherapy market, where consumers have a choice of therapies as if choosing between

brands of soap. Some may welcome such a choice, but free-market solutions only work when consumers have good information about the available options – something that vulnerable and desperate people might not seek out or receive.

This is not to say that all recovered memories are false. Most experts think they can be true. But placing faith in them is dangerous. Certainly they need to be corroborated by independent evidence. And the nature of how they emerged is crucial; any memory that has to be drawn out by a therapist must be regarded as suspect. We need to know more about the circumstances under which memories are suppressed and recovered, and their reliability. Without this, there is an ever-present danger of descending back into voodoo.

There is no doubt that many recent revelations of historical sexual abuse are rooted in reality. Those who went through it deserve recognition, compensation and a chance to rebuild their lives. But if a discredited therapy is allowed to sneak in through the back door and threaten a repeat of previous scandals, there is a danger that genuine victims' stories will be tainted by doubt. That cannot be allowed to happen. ■

Record floods in east US

IT HAS been described as a "once in a millennium" event - but the next might come a little sooner than that.

Record sea surface temperatures in the Atlantic have fuelled downpours of biblical proportions in the eastern US, and the resulting floods have killed 12 people. Climate change could make such events more likely.

Hurricane Joaquin moved north-east over the Atlantic last week. It missed the US east coast but warm, wet air from its outflow combined with a separate low-pressure system to create unusually wet conditions. Last week, this weather reached North and South Carolina. More than 60 centimetres of rain fell between 1 and 5 October in some parts of Charleston County.

The US National Oceanic and

Atmospheric Administration has estimated that there is a 1 in 1000 chance such an event will occur in a given year.

"We think that these sorts of events are more likely to take place when the atmosphere warms up due to greenhouse gases," says Joanna Haigh, co-director of the Grantham Institute for Climate Change at Imperial College London, although she stresses we can't say specifically that these storms are related to climate change.

South Carolina Governor Nikki Haley said some 40,000 people have been left without running water and 26,000 without power.

On Monday, President Obama declared a major emergency, making federal resources available to deal with the disaster.



AP PHOTO/PA/MIC SMITH

South Carolina "once in 1000 years"

Eyes on the prizes

IT'S not often that a 1700-year-old recipe inspires work that leads to a Nobel prize. This year's award for medicine or physiology has gone to three pioneers in the field of parasitic disease, for discoveries

"Together, the anti-parasite treatments have improved the lives of 3.4 billion people around the world"

that have helped in the fight against malaria and roundworm.

Half the prize was awarded to Chinese scientist Youyou Tu. She drew on traditional Chinese medicines to discover artemisinin, one of the most important malaria drugs in use today.

Irish parasitologist William C. Campbell and Japanese microbiologist Satoshi Omura share the other half of the prize for their discovery of ivermectin, which has dramatically reduced the incidence of river blindness and lymphatic filariasis.

Together, the treatments have improved the lives of 3.4 billion

people, said the Nobel committee.

From tiny parasites to tiny particles. The Nobel prize for physics was won by physicists Takaaki Kajita from Japan and Arthur McDonald from Canada, for their discovery of neutrino oscillations, which show that neutrinos have mass.

Neutrinos are ghostly particles with no electrical charge. They were originally thought to be massless, until the prizewinning duo discovered that neutrinos actually change state as they fly through space, and that this metamorphosis requires they have mass.

The pair's discoveries give us an unprecedented insight into matter. "We are very satisfied that we have been able to add to the world's knowledge at a very fundamental level," said McDonald.

Since neutrinos can pass straight through matter, we can use them to peer beneath the Earth's surface, deep into space and even inside nuclear reactors, potentially providing a way to monitor nuclear proliferation agreements (see page 10). Not bad for a particle that is barely there.

Trial expert accused

A SENIOR pathologist whose research challenges "shaken baby syndrome" begins a disciplinary hearing this week.

Waney Squier, a consultant at the John Radcliffe Hospital in Oxford, UK, has identified innocent causes for a so-called "triad" of symptoms previously thought to be caused solely by abuse. She has appeared as an expert witness in several court cases involving alleged abuse.

Squier has now been brought

before the UK General Medical Council, charged with giving evidence outside her field of expertise, failing to be objective, and failing to pay "due regard to the views of other experts".

The GMC would not disclose its reasons for pursuing the case against Squier but other pathologists have described it as a "witch hunt" aimed at preventing her from being an expert witness in the future.

Controversy over the validity of the triad remains. The hearing is expected to last six months.

Europe bans GM crops

IN A way, it's a vote against science. Most of the 28 countries in the European Union, including Germany, France and Italy, have decided to ban their farmers from growing genetically modified crops. Regions within member states, including Scotland, Wales and Northern Ireland, have also joined the exodus.

A total of 19 member states took advantage of rules that permit them to ban the cultivation of GM crops adjudged by Europe's regulators to

pose no risk to human health or the environment. Even if some countries want to grow a new GM crop themselves, they are unlikely to be able to do so. Without a majority yes vote from members, any crop that is scientifically passed as safe should be approved by the European Commission by default, but it has so far consistently failed to do this. Meanwhile, a proposal to ban the import of GM crops for animal fodder looks doomed.

El Niño looming

THE world is preparing for a monster El Niño about to strike.

El Niño emerges when winds blowing west across the Pacific weaken, and warm water spreads

"El Niño has contributed to hundreds of deaths already, but the worst is yet to come"

out east towards South America, dragging rainfall with it.

In sub-Saharan Africa, the International Federation of the Red Cross has launched an emergency appeal as extreme flooding is predicted to worsen food shortages. This week, Kenya issued an alert ahead of expected rains, while Chile and Peru are likely to be hit hard and are making preparations.

Already, El Niño has contributed to hundreds of deaths in a heatwave in India, and this month it pushed temperatures up to near record levels in eastern Australia.

"The worst is yet to come," says Wenju Cai at CSIRO, Australia's national research agency in Melbourne. Some of the most severe effects will likely be in the form of tropical storms, he says, which are not only caused by El Niño but exacerbated by its strength.

The El Niño will intensify in the coming months and probably peak around February.

ASTROBOTIC



Fly me to the moon

Lunar X Prize boost

TOO soon for the moon? A race to land a privately funded mission on the moon just got extended until 2017.

The Google Lunar XPrize aims to encourage the development of private space flight. There are currently 16 teams in the running, and the first to land a robot on the moon, have it travel 500 metres and transmit HD video back to Earth will win the grand prize of \$20 million.

"This is the first contract to send a robot to the moon that has been officially vetted and verified"

An Israeli team called SpaceIL has now announced a contract with US firm Spaceflight Industries to launch its robot on board a SpaceX Falcon 9 rocket. That triggers an extension of the competition, which would otherwise have come to an end this year if no team had a verified contract in place.

Two other teams have contracts to send craft into space. Moon Express announced plans this week to launch with Rocket Labs, a start-up that is yet to go to space, while Astrobotic has had a SpaceX contract since 2011. However, neither contract has been submitted to XPrize for approval.

SCOTT BARBOUR/GETTY IMAGES



Non, nein, no

60 SECONDS

Tall story

Which came first, the giraffe or its long neck? Fossil vertebrae from extinct species related to giraffes have allowed the evolution of its neck to be pieced together - and the work confirms that long necks had begun to appear before the giraffe family itself evolved (*Royal Society Open Science*, DOI: 10.1098/rsos.150393).

Robot taxis shop-bound

Your driver could soon be a robot. Trials of driverless taxi cabs are due to start in Fujisawa, Japan, next year. The cars will take about 50 people on 3-kilometre shopping trips. Operator Robot Taxi hopes to commercialise the service in time for the Tokyo 2020 Olympics.

Asteroid named

Pack your bags, we're going to Ryugu. The Japan Aerospace Exploration Agency has given a name to the target asteroid for the Hayabusa2 spacecraft, which launched last year. The probe will arrive at the rock, formally known as 1999 JU3, in 2018 to collect samples.

If the price is right

When the going gets tough, some search for ways to make their body pay. Online searches related to sperm, egg and blood donations increase during recessions, and researchers suggest that search statistics may even help predict national trends in donation rates (*Canadian Journal of Urology*, vol 22, p 7923).

Safe Harbour in doubt

This might spell trouble. On Tuesday, the European Union's Court of Justice invalidated the agreement allowing personal data to be moved from the EU to the US for processing. The ruling against the 15-year-old Safe Harbour deal threatens the business model of companies which use US servers to process European users' data, including Google, Apple, Microsoft and Facebook.

Ungreen and not-so-pleasant land

The UK could face legal action over climate change, reports **Michael Le Page**

IF IT fails to cut emissions of greenhouse gases, the UK could be taken to court.

The government was warned earlier this year that the country was not on track to meet its climate goals. But instead of intensifying its efforts, it has blocked a series of green measures, veering even further off course.

The announcements have disappointed groups from climate change campaigners to business leaders. The news is already damaging investment in sustainable technologies. "It's very severe," says Jeremy Leggett, director of solar energy company SolarCentury. "The magnitude of the cuts is unexpected even in our worst case analyses."

The UK's "disastrous assault" on environmental policies has not gone unnoticed internationally. There are fears that it could undermine efforts to get countries to commit to big emissions cuts at the UN's December summit in Paris.

Lawyered up

So what happens next? The government is expected to say that the policies it reversed were flawed, and claim that it has an alternative strategy. This relaunch is expected before December, to stop Prime Minister David Cameron losing face when world leaders meet in Paris, says Doug Parr, chief scientist at Greenpeace UK. "But whether it is a meaningful attempt or PR we still have to find out."

The UK's own climate targets have been enshrined in law with the 2008 Climate Act, which requires it to cut emissions by 80 per cent by 2050. If the government fails to get back on course to meet these targets, it can

be taken to court. ClientEarth, a group of activist lawyers, has already successfully sued the UK government over its failure to reduce air pollution, and has told *New Scientist* that it is considering such action on the climate targets.

"By turning climate change targets into law, the UK made a promise to meet them. But already we are starting to see the strength of that commitment

tested," says head of ClientEarth James Thornton. "This law is not for show – it is a law like any other, which has real consequences for those who don't follow it."

Prime ministers from Tony Blair onwards have claimed that the UK is leading the world in tackling climate change. And on paper at least, they can point to apparently impressive progress. The UK's emissions are now 36 per

cent below 1990 levels, if the provisional estimate of an 8 per cent fall in 2014 is correct.

But little of this fall is due to a switch to renewable energy. In fact, earlier this year the EU warned that the UK is not on track to meet its target of getting 15 per cent of its energy from renewables by 2020. That's despite being set a lower target than most: the EU-wide target is 20 per cent.



JOHN HARRIS/REPORTDIGITAL.CO.UK

Sheep don't like it either

In this section

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What's more, the single largest source of renewable energy in the UK is not wind or solar, but biomass. Much of this energy comes from coal plants converted to burn wood pellets. Critics argue that this does not reduce emissions nearly as much as claimed and could even be increasing them.

Instead, the fall is due to a switch from coal to gas, a decline in heavy industries and "exporting" emissions to other countries (see graph, right). Nor does the 36 per cent figure include emissions from aeroplanes, which have increased massively since 1990.

The fall in emissions is a fragile achievement, says Matthew Bell, chief executive of the Climate Change Committee – the independent organisation set up to monitor progress on the Climate Act. The big drop in 2014, for instance, was largely to do with a warm winter and less coal being burned, as well as a rise in the price of coal. There's nothing to stop energy companies burning more coal if it becomes cheaper.

On 31 June, the Climate Change Committee warned in its annual report that a range of policies intended to boost renewable energy and increase energy efficiency were due to expire in the next few years. It said this would lead to the UK missing its targets for emissions for the 2023 to 2027 period. The committee made several recommendations, such as extending some subsidy schemes to 2025 to encourage investment, implementing plans requiring new homes to be "zero carbon" and maintaining support for electric cars.

The government has not only disregarded the committee's recommendations, it has done the opposite in several cases (see timeline, right). Instead of extending subsidy schemes for solar and onshore wind, for example, it plans to cut them.

Why? Parts of the Conservative party have long opposed wind

farms. And some environmental policies are funded by green levies added to homeowners' energy bills, which the government wants to remove. But the government seems to have cut policies it doesn't like without any thought of the impact on businesses, investment and its

"The government seems to have cut policies without any understanding of its legal obligations"

credibility – and without any understanding of its legal obligations.

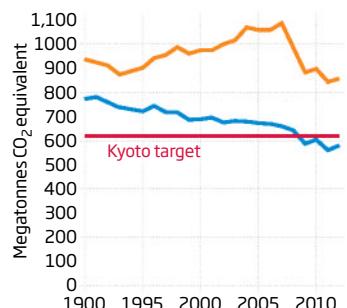
"One can only conclude that they have been listening too much to powerful lobbyists," says Leggett. The Climate Change Committee is concerned enough that it took the unusual step of writing to the government.

"The committee is aware that the cumulative impact of these announcements has drawn into question the speed at which the UK is going to progress to meeting its climate obligations," says Bell. "Action is needed and fairly soon."

So with the government cutting support for onshore wind – the cheapest renewable energy source – as well as solar and biomass, what's the alternative?

Just an illusion?

The UK claims the greenhouse gas emissions it produces have fallen steadily, meeting its international target set under the Kyoto Protocol



But the picture is very different if you look at the **total emissions the UK is responsible for**, which includes those from goods produced in other countries but consumed in the UK

One possibility is more nuclear power. But the costs of the one new reactor already planned at Hinkley Point are soaring. Not a single reactor of this design has yet been completed – and we can't spare the time it would take to build more.

Then there's fracking. But few believe the claim that fracking can "bridge the gap" to renewables. It may not be commercially viable, either. The US fracking boom is turning to bust because of lower gas prices. A recent fracking-industry funded report concluded that this process in the UK should not be subsidised and would have to be combined with carbon capture and storage – which would make it even more expensive. It could also be a bigger vote-loser for the Conservatives than onshore wind.

Massive U-turn

So it's far from clear how the UK can get back on track to meet its targets. "They are going to have to do a massive U-turn during this parliament," Leggett argues.

Failing to get back on track would leave us in unknown territory, says Bell. The UK may not start breaching its target until the 2020s, but Karla Hill, a member of the ClientEarth team, says the terms of the Climate Act mean legal action could be taken before this point. "In our view, the government could face legal action sooner rather than later," she says.

In theory, the UK could repeal the act but no one *New Scientist* spoke to thought this was likely. For one thing, it would still have legally binding obligations to increase renewables and cut emissions as a member of the EU.

Other developed countries have far worse records than the UK. Japan's emissions have been rising, for instance, while Canada withdrew from the Kyoto Protocol altogether. So it would be wrong to describe the UK as a climate villain. But it is now very far from being the leader it claims to be. ■

2015: THE GREEN ANNUS HORRIBILIS

March 2015: The UK's chancellor announces £1 billion worth of subsidies for North Sea Oil. In 2009, G20 countries including the UK pledged to phase out "inefficient" fossil fuel subsidies.

16 June: The EU says the UK is set to miss its renewables target.

18 June: New onshore wind farms will be excluded from a subsidy scheme from 1 April 2016.

25 June: The UK says it will sell off up to 70 per cent of its Green Bank, set up to lend money to risky green schemes.

30 June: The Climate Change Committee warns the UK is not on course to meet targets after 2020.

8 July: Budget changes reduce the incentive to buy low-emission vehicles.

10 July: The zero carbon homes plan is scrapped. From 2016, all homes built in the UK were supposed to be carbon neutral.

22 July: Plans to cut subsidies for solar power and for converting power plants to use biomass are announced.

23 July: The Green Deal plan to help people make homes more energy efficient is scrapped.

4 September: The energy minister admits nothing is being done to ensure coal use doesn't rise again if prices drop.

16 September: The UK falls from the top 10 in a list of the best countries in which to make renewable energy investments.

2 October: Plans to build £1 billion tidal power scheme in Wales are delayed by a year.



No help with solar

PAUL HACKETT / REUTERS

Danger of 'false' memories returns

Clare Wilson

UNDER the soaring vaulted ceilings of the Victorian Gothic edifice that is the UK's Royal Courts of Justice huddles a family that has waited 10 years to learn the truth about a woman's death.

I have joined them at the inquest for Carol Myers, born Carol Felstead, who in 2005 was found dead in the bedroom of her London flat aged just 41. But understanding what happened that day is not the Felstead family's only motive.

They want to raise awareness of her experience at the hands of mental health professionals in the name of treatment, and

"Families have been torn apart by the fake memories gained through recovered-memory therapy"

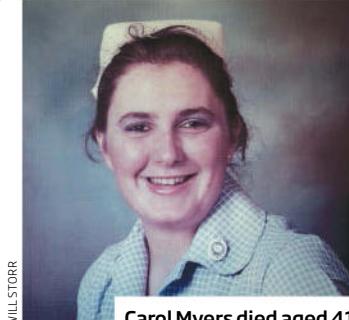
the dangers that the techniques used on her still pose.

Myers underwent recovered-memory therapy, which coaches people into "remembering" things from their past, often while hypnotised or under the influence of strong tranquilisers.

The approach is now shunned by most mainstream professionals because of the danger of creating false memories – leading patients to recall events that didn't actually occur. Yet some psychotherapists still use the techniques.

Researchers are warning that the current publicity around historic abuse claims could lead to a resurgence of the idea of recovering memories. "The real victims are giving credibility to those who are more questionable," says Elizabeth Loftus of the University of California, Irvine.

It may seem incredible that anyone can be mistaken about



Carol Myers died aged 41

being abused, but there have been countless cases where claims were proven to be false. In the 1980s and 1990s there was a global epidemic of false satanic abuse claims from children, typically thanks to leading questioning from misguided social workers.

A 1994 UK government report into 84 satanic abuse claims found that none was supported by physical evidence, such as scars left on alleged torture victims or forensic evidence from rooms that were supposedly the sites of multiple murders.

Loftus's work has been pivotal to our understanding of the field. She has shown that it is possible to give people false childhood memories, such as getting lost

in a shopping mall or knocking over a punch bowl at a wedding.

She did this by first convincing people the event had happened, by claiming their parent had told her. Then she asked them to imagine it. Over repeated sessions, about a third of the subjects ended up with false memories.

Loftus says this is similar to what happens in recovered-memory therapy. Patients are typically told that they must have been abused, because that is the most likely explanation for their troubles, and that they will only get well if they recall and confront the memory by imagining it.

Partly thanks to Loftus's work, many doctors' and therapists' organisations now warn against such techniques. "The consensus is that recovered memories can be accurate or inaccurate or a mixture," says Bernice Andrews of Royal Holloway, University of London, who acts as an expert witness in court cases. She says memories that re-emerge spontaneously are more likely to be real than those from recovered-memory therapy.

However, the therapy has not yet died out (see "Turning fantasies into memories", below). A recent survey of UK clinical psychologists and hypnotherapists found that about 1 in 6 think such memories are usually or always accurate. "There are families that

TURNING FANTASIES INTO MEMORIES

Elaine (not her real name) went to see a hypnotherapist four years ago because of anorexia. He told her that the cause of her trouble was a long-buried childhood trauma. "He said it couldn't have been anything other than sexual abuse," she recalls. A typical session would involve Elaine being hypnotised and then asked to imagine "the worst thing that could possibly have happened to her".

She wrote in a diary at the time: "I could never have been this ill for so long without something traumatic

having happened... if I just persist with this, surely the memory will pop out." Eventually, though, Elaine grew uneasy about her therapist, and couldn't reconcile what he said with the knowledge that her childhood was, in fact, happy. She discovered the British False Memory Society (see main story), who warned her of the dangers of the therapy.

Looking back, Elaine cannot understand why she fell for it. "I guess I just handed myself over to the medical profession, as I saw him."

BERTRAND MEUNIER/TENDANCE FLUO



are torn apart on the basis of these false memories," says Christopher French of Goldsmiths, University of London, who led the survey.

One such family was the Felsteads. Carol left home in her 20s, and unbeknown to her parents at the time, saw several therapists, some of whom espoused recovered memories.

Her medical notes record that she claimed to have been satanically abused by her parents – a charge they vehemently deny. She never discussed her accusations with them but, unsurprisingly, she stopped visiting home and changed her surname.

Jean La Fontaine of the London School of Economics, who led the 1994 inquiry into satanic abuse, says the current interest in historic sex abuse cases risks a resurgence of the credulous



Just a fantasy?

hysteria we last saw in the 1990s. "That's the danger," she says.

Claims were made earlier this year, for instance, that Jimmy Savile, a British celebrity who undoubtedly assaulted many people over decades, was part of a satanic abuse circle. "That rings alarm bells for me," says French.

French is concerned that senior police officers have publicly stated that, above all else, victims will be believed in historic cases. One case was described as "credible and true" even before police investigated. "For a long time, victims weren't listened to, but now the pendulum's gone the other way," he says. In the US, Loftus says allegations of historic abuse by the clergy are playing a similar role.

Madeline Greenhalgh of the British False Memory Society, which helps subjects of false

abuse claims, says she knows of two families who believe their relatives' fantasies have been triggered by news coverage of historic abuse cases.

Carol Myers' inquest recorded an open verdict. Hers was a difficult story to unravel because by the time of her death she had interrelated mental and physical illnesses. It was not possible to determine if she took an overdose of morphine or if her heart simply stopped because of the many medications she was taking, on top of a physical weakness.

But whatever the cause of death, her brother Kevin is angry that she spent the last half of her life cut off from her family and in great distress. "She was failed by people who were supposed to help her," he says. "This shouldn't be allowed to happen." ■

Invisibility cloak could hide mice from snakes

THE thermal rays of mice and men often go awry. An invisibility cloak built for a mouse could hide warm bodies from predators with thermal vision - and could scale up to hide humans from heat-seeking missiles.

Invisibility cloaks, which harness the unusual properties of light-bending metamaterials, have shown theoretical promise for years. But

"The cloak was tested by hiding the toy's lower body from the camera - its head seemed to float in the air"

outside of dramatic illusions made with lenses, these haven't been cloaks that would fool your eye. To redirect the short wavelengths of visible light requires tiny structures, so instead early designs deflected longer wavelengths like microwaves. Cloaks have also struggled to handle many wavelengths of light at once.

Now, a team at Zhejiang University in Hangzhou, China, has taken a significant step forward by making a cloak for infrared radiation, whose wavelengths are only just too long to see. All animals - including humans - emit infrared as heat. Snakes can sense this radiation even in darkness, using it to hunt down their prey.

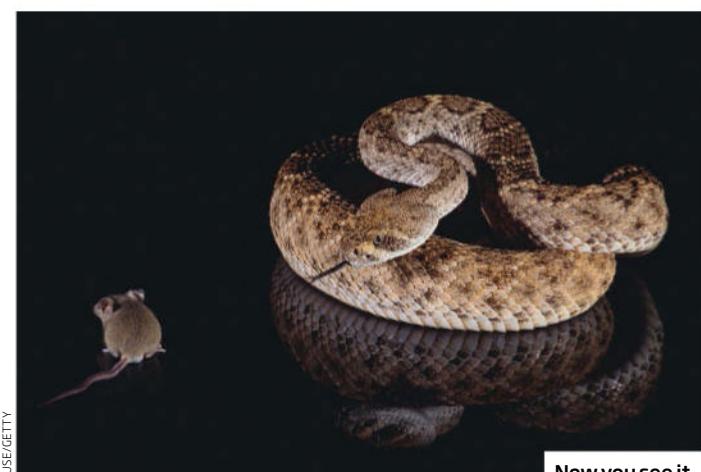
"We want to simulate the scene of catching a mouse," says team member

Hongsheng Chen. His team did that by getting a snake's-eye view of a toy mouse heated to 35°C through a thermal camera.

They built an accordion-like structure from germanium, leaving a 2.7-centimetre-wide cavity in the middle for the toy mouse. The camera was placed on one side. The germanium sent infrared rays from behind the mouse on a curved path around the cavity, then bent them back into straight lines for the camera, making it seem like they had travelled through the structure. Rays emitted from inside the cavity were blocked.

The team tested it by hiding the lower body of the toy mouse from the camera - its head seemed to float in the air. They also showed that the cloak could work as the environment around the toy varied between 30°C and 45°C (*Advanced Optical Materials*, doi.org/75c).

"To my knowledge this is the first attempt to cloak against thermal radiation, and the authors introduce some novel design concepts that take forward the practical issues of designing a cloak," says John Pendry of Imperial College London, who pioneered the mathematics behind invisibility cloaks. "With the basic theory done and dusted, cloaking is moving on to practical considerations." Joshua Sokol ■



Now you see it...

Nuclear checks, the neutrino way

Jacob Aron

IT ISN'T yours, but you'd like to peer inside without annoying the owner. Such is the challenge of international nuclear inspections. An experimental kind of particle detector could come in handy, giving us a new way of finding out whether a reactor is producing material for weapons.

Earlier this year, Iran agreed a deal with major world powers to limit its nuclear activities, promising it will allow monitors from the International Atomic Energy Agency (IAEA) to inspect its plants and ensure they are being used for peaceful purposes.

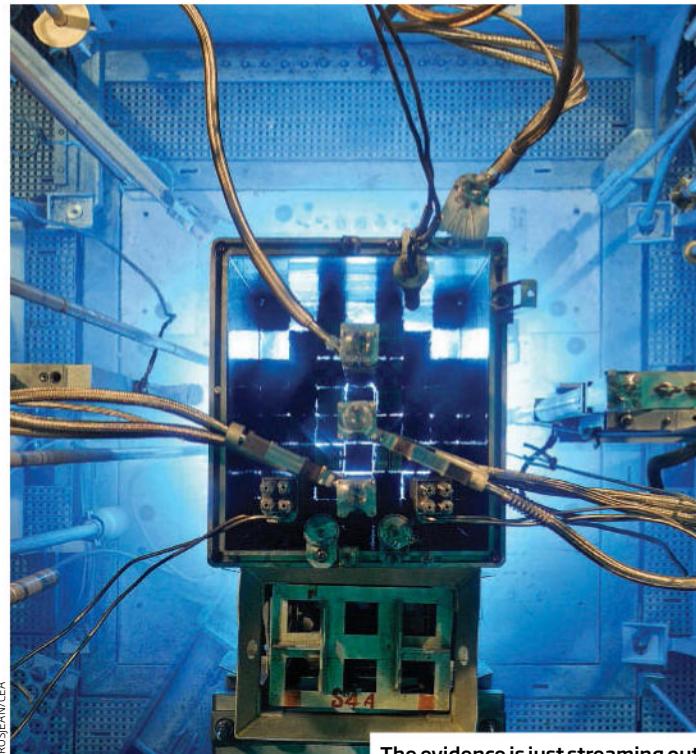
The deal is built on fragile trust – Iran doesn't want to reveal any more of its nuclear secrets than it has to. A device to monitor reactors remotely, with no need for foreign inspectors to visit, would help.

As it turns out, we know how to build specialised detectors for particles called neutrinos. Produced by nuclear reactions, they barely interact with ordinary matter, so stream away from reactors and can be picked up far away with a suitable instrument.

For the past year, researchers in France have used one such detector, dubbed Nucifer, to monitor a small reactor next door. Nucifer is full of a liquid scintillator that flashes on the rare occasions when a neutrino interacts with it. The rate at which this happens reveals the activity level inside the reactor.

Despite the presence of other energetic particles, the team was able to create shielding for Nucifer and get useful readings. Over the course of 145 days, the team could detect when the reactor was running, and track the amount of plutonium-239 inside (arxiv.org/abs/1509.05610). This isotope is especially useful for producing nuclear weapons, so any sudden change in its level suggests armaments may be the reactor's actual purpose.

Researchers have already built detectors of this type in Russia and the US, but they were one-off creations and required frequent maintenance, which wouldn't be practical in the context of monitoring. "With Nucifer, we wanted to improve the performance and use off-the-shelf parts," says team member David



The evidence is just streaming out

Lhuillier of the Saclay Nuclear Research Centre near Paris.

The neutrino output of a full-scale reactor would be big enough that the detector could be installed at a discreet distance, with inspectors logging in remotely. The team is now trying to find one for further tests. "We could put the detector in place, close the door and leave it like that for one year, in conditions very close to what the IAEA inspectors would like to

see," says Lhuillier. But it will probably be at least 15 years before it is ready for real-world use.

The IAEA told *New Scientist* that they have no imminent plans to deploy the technology. But Patrick Huber of Virginia Tech in Blacksburg, who works on similar detectors, says Nucifer is a great step forward. "We're not quite there yet, but it goes a very long way from where we were 10 years ago," he says. ■

One-two punch may have killed off dinosaurs

IT WAS one thing after another for the dinosaurs. The famous asteroid that hastened their demise touched down in the middle of a period of climate change caused by intense volcanism.

The resulting seismic shock may have then triggered even more eruptions, suggesting a one-two punch saw off *Tyrannosaurus* and co.

This interpretation could help bring

together two schools of thought on what caused one of the largest mass extinctions in our planet's history, 66 million years ago.

The dominant theory is that the asteroid impact was chiefly responsible for wiping out three-quarters of the species then alive.

Another line of thought is that climate change triggered by vast volcanic eruptions led to the downfall of the dinosaurs. A region called the Deccan traps in modern-day India oozed more than a million cubic kilometres of lava over about 800,000 years, releasing sulphur

dioxide and carbon dioxide, and warming the atmosphere.

Now there is evidence that the worst of these lava flows happened after the impact. Paul Renne of Berkeley Geochronology Center in California and his team reached this conclusion by using argon isotopes to date Deccan rocks (*Science*, doi.org/74q). "Suddenly the lava flows erupting in the Deccan traps are much

thicker and much more widely distributed," Renne says. "Thousands of kilometres are affected."

The finding backs up a theory published earlier this year by Mark Richards, a colleague of Renne's at Berkeley. The shock waves from the Chicxulub asteroid – equivalent to those of a magnitude-11 earthquake – may have agitated a plume of mantle material fuelling the Deccan traps from below, he says.

Continued eruptions for another half a million years may then have made it harder for ecosystems to bounce back. Joshua Sokol ■

"Suddenly the lava flows erupting in the Deccan traps are much thicker and more widely distributed"



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Thrown up by the sea?

100-metre waves are a threat today

Joshua Sokol

WITH waves taller than 100 metres, it's no wonder they are called megatsunamis. After part of Cape Verde's Fogo volcano fell into the sea around 70,000 years ago, a wave 170 metres tall slammed into nearby Santiago island, now home to over a quarter of a million people.

That's the conclusion of work by Ricardo Ramalho, now at the University of Bristol, UK, and his team at Columbia University in New York. They say that the volcano has since grown back to its pre-disaster proportions and may be in for another catastrophic collapse. What's more, we may be underestimating the risk of similar events on other volcanic islands.

Megatsunamis are defined as being at least 100 metres tall at their source. In contrast, the tsunami after Japan's 2011 Tohoku earthquake topped out at 40 metres.

In theory, giant waves can be triggered by huge amounts of

material crashing into the ocean: impacts from space, for example, or the collapsing flanks of volcanic islands. But clear evidence for a large collapse happening fast enough to cause one has so far been lacking. Given the abundance of volcanic islands, it would be good to know if it is a possibility.

While working on a separate project, Ramalho noticed huge boulders scattered across Santiago's landscape, as high as 220 metres above sea level and

"When the side of the Fogo volcano cracked off, it triggered a wave up to 170 metres tall"

650 metres from the coastline. Some weigh more than 700 tonnes and are made of rock similar to that at the shore – suggesting they were deposited by a large wave.

By combining data on the boulders with the pattern of rock sediments at lower altitudes, his team estimated the height, path and date of the wave. That date

matched with Fogo's partial collapse, some 73,000 years ago.

Ramalho's team says the event triggered a wave up to 170 metres tall, that travelled 55 kilometres to the shores of Santiago (*Science Advances*, doi.org/74r).

"That's a huge tsunami. Even if their modelling overestimated the size, that's still a huge tsunami," says Bruce Jaffe of the US Geological Survey in California. He says work like this is crucial to understanding the risk megatsunamis pose in the present.

We still don't know how often crumbling volcanoes lead to giant waves, but Ramalho's team suspects these events may be more frequent than thought. There are numerous at-risk ocean volcanoes in the Caribbean and elsewhere, says James Goff of the University of New South Wales in Sydney, Australia. "We have been expressing increasing concern about flank collapse events in Pacific islands," he says.

If and when they do happen, they are mostly a risk for nearby areas. This is because unlike the waves made by earthquakes, in which a fault movement pushes the wave like a paddle, megatsunamis tend to lose power more quickly over distance – like the spreading ripples from a pebble dropped into a pond. ■

Targeted drugs could kill only harmful bugs

SET your phages to stun. Researchers have devised a way to engineer a class of bacteria-destroying viruses to make them more clinically useful. The phage viruses could eventually be used to kill disease-causing bacteria in the body while leaving our "good" bacteria unharmed.

Many phage viruses infect and replicate inside bacteria, killing them. This makes phages a possible alternative to antibiotics as resistance to these drugs grows. What's more, most phages infect only one species or even a few strains within a species; antibiotics aren't so selective.

But that specificity is a problem: it might not be clear which pathogenic bacterial strain is present in an infection, so a cocktail of several phages might be needed to guarantee effective treatment. Each may have to pass regulatory approval separately.

Timothy Lu and his colleagues at the Massachusetts Institute of Technology aim to get round this by making a single phage modifiable with bacteria-attacking machinery from other phages. In theory, that could reduce regulatory hold-ups.

Phage DNA is difficult to manipulate in the lab, so Lu's team made their modifications while the phages were in yeast. They swapped in genes from other phages to change the phage tail – a needle that punches through a target bacterial membrane. They could then direct the virus to target new bacteria.

"We built a phage design system that is a lot more efficient than anything that came before," says team member Sébastien Lemire.

The phage normally kills *E. coli*, but by swapping in different tails, the team made it kill at least 99 per cent of either *Yersinia* or *Klebsiella* bacteria (*Cell Systems*, doi.org/74j).

"It may well make it possible to get new therapeutic phages much more quickly," says Elizabeth Kutter at Evergreen State College in Olympia, Washington. Anna Nowogrodzki ■

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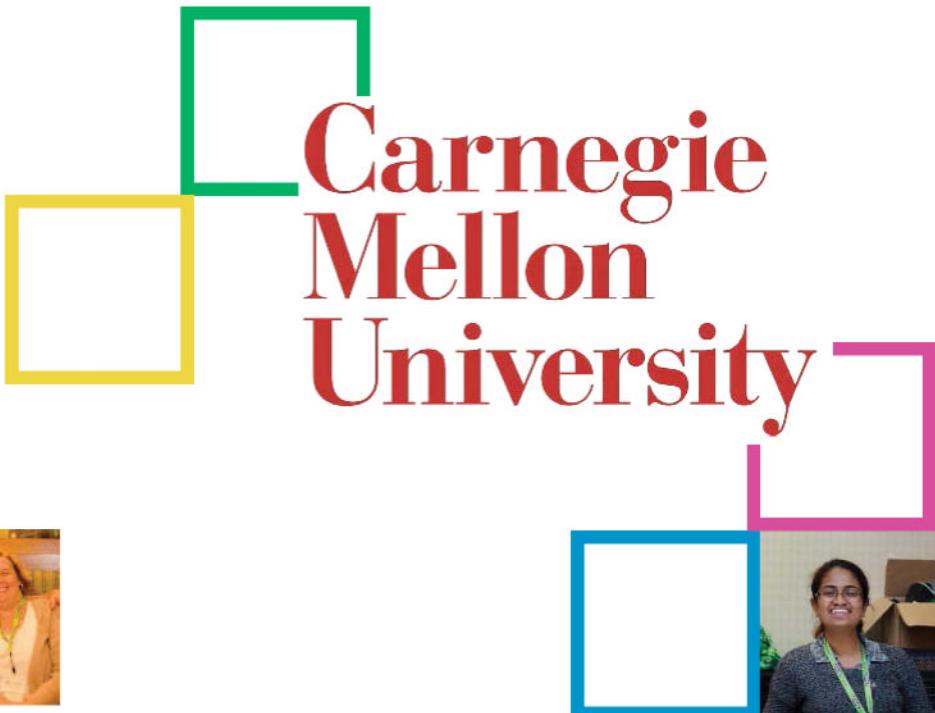


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Wildlife now thriving around site of worst nuclear accident

CHERNOBYL: wildlife haven. Deer, elk and wild boar are as abundant around the site of the world's worst nuclear disaster as in the region's nature reserves - and wolves are seven times as common.

Some 116,000 people fled the radioactive fallout from the Chernobyl power plant when its reactor exploded in 1986, and another 220,000 were later resettled. In total a zone covering around 4200 square kilometres split equally between Belarus and Ukraine was vacated.

An analysis of field data by Jim Smith of the University of Portsmouth, UK, which had been collected by his

colleagues in Belarus, is the largest study on wildlife in the area since the accident.

Roe deer, elk, red deer, wild boar and wolves were surveyed between 2008 and 2010 by counting tracks left in snow. Their abundance was compared with that seen between 2005 and 2010 in four uncontaminated nature reserves of similar size and habitat in Belarus. The density in Chernobyl matched or exceeded those in other reserves. A similar picture was seen when they compared wildlife numbers in Chernobyl with those in the Bryansk Forest reserve 250 kilometres away in Russia (*Current Biology*, DOI: 10.1016/j.cub.2015.08.017).

"Whatever negative effects there are from radiation, they are not as large as the negative effects of having people there," says Smith.

Plastic foam turned into artificial heart

A HEART of foam could replace your own. Researchers inspired by soft robots have built a pumping artificial heart that could one day beat inside your chest.

Recent years have seen the development of soft robots that mimic snakes and tentacles. They are made from pliable plastic and powered by compressed air that makes them flex and move.

But most of these devices are

limited to simple, flat shapes by the network of tubes required to deliver air, says Robert Shepherd of Cornell University in Ithaca, New York. That's why his team builds its robots using a solid, porous plastic foam that naturally has an interconnected network of tubes to let air flow. A solid plastic coating seals everything inside like a skin.

The team constructed a simple

model of the human heart that only has two chambers, compared with our four. Powering it with air makes it flex and pump water between the chambers.

"We believe it has the potential, after further development, to be a viable replacement for a heart," says Shepherd. Existing artificial hearts have multiple moving parts, which increases the chance of failure, but the new device is a single piece of material (*Advanced Materials*, doi.org/f3gcfh).

Reboot insulin cells to treat diabetes

INSTALL new software.

Ordinary pancreas cells can be reprogrammed to produce insulin, potentially offering a way to treat type 1 diabetes.

People with type 1 diabetes don't produce insulin, making it difficult to manage blood sugar.

So Philippe Lysy at the Catholic University of Louvain (UCL) in Belgium and his colleagues took pancreatic duct cells from dead donors. These cells don't normally produce insulin but have a natural tendency to differentiate into specific cell types. Lysy's team managed to turn them into insulin-producing cells by inserting a genetic switch to activate them.

The team implanted the altered cells in mice with a form of diabetes and found they secreted insulin. They reported the work at a European Society for Paediatric Endocrinology meeting in Barcelona, Spain, last week.

Tree frogs make up tunes to win a mate

IT'S the king of amphibian ad-libbers. Male *Gracixalus* tree frogs of Vietnam improvise melodies every time they sing.

To our ears, the songs of *G. gracilipes*, *G. supercornutus* and *G. quangi* sound like birds chirping. But each performance is unique in its complexity, length, volume, pitch and structure. With most other frogs, individuals have their own song and they keep to it.

"We don't know why they have such complex calls," says Jodi Rowley from the Australian Museum Research Institute in Sydney, whose team discovered *G. quangi* in 2010. "They say more than your average frog."

The calls serve to attract a mate and may also mark out territory (*Amphibia-Reptilia*, doi.org/735).

Musicians have mirror-like brains

YOU really can have a head for music. The brains of musicians respond more symmetrically to it, and the size of the effect depends on the instrument they play.

The corpus callosum – the strip of tissue that connects the brain's left and right hemispheres – is thought to be particularly large in musicians. Iballa Burunat at the University of Jyväskylä in Finland and her team looked at whether this makes the neurons in the two hemispheres more likely to fire in sync.

They used an fMRI scanner to look at the brains of 18 trained musicians and 18 people with little or no musical training. While in the scanner, all participants heard three pieces of music, each in a particular style. The team found that activity in musicians' brains did indeed seem to be more symmetrical, at least in regions involved in motor control (*PLoS One*, doi.org/733).

What's more, the effect is more marked in keyboard players than in those who play string instruments. "It is surprising that the effect is instrument-specific," says Marcus Pearce at Queen Mary, University of London.

Burunat thinks that this is because both hands are used to strike the keys on a keyboard, whereas with a guitar, say, one hand holds down the strings while the other strums or plucks.



Grass disguises seeds as droppings to trick dung beetles

OUTSMARTED by a plant. One species of grass has evolved to deceive dung beetles into dispersing its seeds by making them look – and smell – like antelope droppings.

Dung beetles are suckers for dung, which they usually roll into balls and bury as a food store for themselves or their eggs. The *Ceratocaryum argenteum* grass, which is endemic to the De Hoop Nature Reserve in the Western Cape province of South Africa, has evolved to take advantage.

Its seeds are 1 centimetre long,

round and brown – just like the droppings of a species of antelope called a bontebok. What's more, the seeds also emit many of the volatile chemicals found in herbivore faeces.

Jeremy Midgley at the University of Cape Town in South Africa and colleagues left 195 seeds on the ground tied to fluorescent threads to see what happened to them. More than a quarter of them were taken away and buried by beetles within 24 hours, typically about 20 centimetres away from where they were left.

When the team analysed the volatile chemicals made by the seeds, they were amazed at the variety of molecules produced and their similarity to those found in antelope dung – even though the antelope don't eat this particular grass. "There has been a lot of chemical evolution going on to get the beetles to do the job," says Midgley.

This is the clearest known example of plants deceiving animals to help them disperse seeds, Midgley says (*Nature Plants*, DOI: 10.1038/nplants.2015.141).

Brain quakes could help spot disease

YOUR brain is buzzing. Analysing those natural vibrations might help spot tumours and other abnormalities – now an algorithm used to study earthquakes has been adapted to do just that.

The elasticity of different parts of the body is a useful way to tell if something is wrong. Ultrasound scans that measure the elasticity of the liver, for example, can show up conditions such as cirrhosis.

Ultrasound can't pass through the skull but MRI scanners can be modified to measure elasticity when tissues are shaken. Unfortunately, shaking the head causes headaches.

So Stefan Catheline at INSERM in Paris, France, has come up with an alternative: take advantage of the brain's natural vibrations. "When blood is pumped into the brain it pulsates," he says.

Catheline took an algorithm that geologists use to analyse Earth's vibrations, and incorporated it into a modified MRI scanner. His team was then able to measure the natural vibrations in the brains of two healthy volunteers – information that could ultimately help identify anomalies associated with disease (*PNAS*, DOI: 10.1073/pnas.1509895112).



REUTERS/MIGUEL VIDAL

The human version of a fish shoal

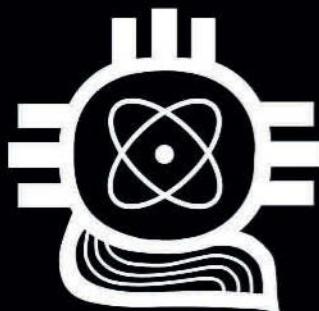
CYCLISTS school like fish. The physics of how a group of individuals stays together may be the same whether they are athletes or animals.

Pelotons are groups of cyclists that form during mass-start races. Hugh Trenchard, a former competitive cyclist and self-taught physicist, produced computer simulations of various pelotons to study them.

He found that they change from roughly circular to single file as the front rider speeds up. The peloton stays united because slower cyclists get an energy boost from the slipstream of riders ahead of them.

Only if this boost isn't enough to compensate for these riders' lower top speed does the peloton begin to fragment. Taken together, this means that the shape and size of the peloton is determined by each cyclist's individual speed (*Applied Mathematics and Computation*, doi.org/7wt).

Trenchard calls this "proto-cooperative behaviour" because it emerges when individuals work together unintentionally. He is now working with biologists to study whether his model applies to schools of fish when they flee predators.



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Archives live forever

In the future, historians will try to work out how we lived. It means we need to change how we record knowledge, says **Hal Hodson**

A YOUNG woman walks through a desolate New York City 1000 years from now. Society has fallen. She comes upon the basement of the New York Public Library. Forcing the door she finds caverns of hard drives. The world's knowledge was once stored here, crucial information for getting by with ease: how to make medicines, how the internal combustion engine works, how to plough a field. But the hard drives are long dead, and she doesn't have a way to read them anyway.

This scenario is the extreme end of a situation that archivists and data preservationists want to avoid, one in which humanity's cumulative knowledge is lost. Now, new ways of storing digital information are giving us a shot at preserving our records, so that our descendants can know their past better than we know ours.

Until the 21st century, libraries preserved cultural knowledge in the form of books. But with humans and their computers now generating more data every year than the entire planet did up until 2003, how we store and preserve

that data has to change. As time passes, hard drives fail, web pages disappear and valuable data stored by companies can vanish if the firm goes bankrupt. And that's assuming we still know how to access obsolete formats.

Group 47 in Woodland Hills, California, is working on ways to get around the fact that our drives

"We're collecting billions of digital objects, things documenting people's fears, loves and thoughts"

and discs have a limited lifespan. Instead of writing 1s and 0s as magnetic signals, they write them as microscopic dots onto metal tape, using a laser in a system called DOTS. The tape is then stored in cartridges. A high resolution digital camera can read the data back, but all a future human would need to retrieve the image is knowledge of binary code and a microscope. The firm says the tape should last hundreds of years without degrading and, crucially, doesn't need any special climate-controlled storage.

The company received funding from a US intelligence agency last year to develop a prototype, and is now raising funds to build a commercial version. The medium is designed to guide someone with no knowledge of hard drives or computers to read its data – all 1.2 terabytes of it. "It's just like the disc on the side of the Voyager spacecraft," says Rob Hummel, Group 47's president.

Hummel says he sees demand for this kind of offline storage that will last indefinitely. For example, the government agency he dealt with wanted to back up the data contained in 40 football fields' worth of datacentres. "They want to keep it forever – they don't actually say forever, they say for the life of the republic," he says.

It's not just government agencies that want to keep things on record indefinitely. Future historians will need a way of accessing the incredible explosion of information that has taken place over the past 15 years. Ian Milligan, a digital historian at the University of Waterloo in Canada, says digital records, like web pages

MIHAEL GULSHKOV/GETTY

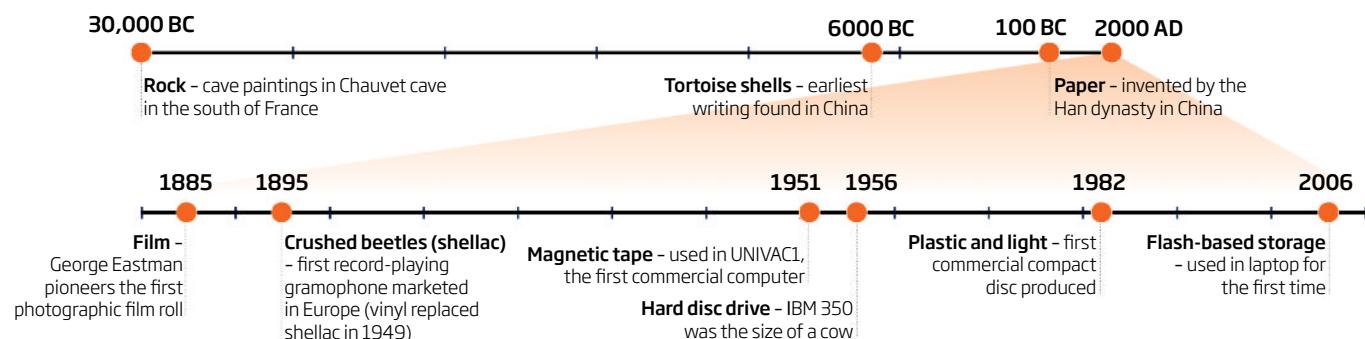


and personal blogs from before the dotcom boom, give historians insights into the lives of normal people. "Starting from about 1996, we're collecting billions of digital objects, things documenting the lives of everyday people, their fears, their loves, their thoughts," he says.

That means finding ways to

Information overload

How we store information has changed over time





How do I read this?

store and then search our history is vital. But the scale is daunting and goes beyond web pages. "We're letting enormous amounts of human information be gathered," says Jason Scott of the non-profit organisation Internet Archive. "Cellphones, writing, ubiquitous and constant photos."

New history

Even the seemingly uninteresting data about our working lives that companies store – emails, databases, HR records – could one day be a fascinating source for a historian who wants to learn more about the early 21st century.

But having a medium that lasts without degrading is no good if people in the future can't read what's written on it. So Group 47 is also working on storing digital data in a format that will never become obsolete.

"Say we've solved the media

problem," says Hummel. "You can put this media on the shelf and it will be there decades later waiting for you. What about the file format issue? If I gave you a WordPerfect file from 1985 that is in perfect condition, you won't be able to open it, because the software doesn't exist anymore."

So Group 47's Dan Rosen has devised a system called bitplain that doesn't save data in a specific format. An image, for instance, isn't stored as a JPEG but is broken down into its smallest components – the 16 or 24 individual bits that make up each of its pixels. The value of each bit – a 1 or a 0 – and their arrangement, is then burned into the metal.

Writing files in bitplain does have a downside, however: it needs more data than other formats. A 4K movie generates 8 terabytes of data. Each DOTS cartridge holds 1.2 terabytes, so that's seven cartridges per movie. Archiving

the same movie as bitplain would require 10 cartridges. "Two more cartridges, but now you are in a format that lasts forever and there is no fear about being able to retrieve it," says Hummel.

But for David Rosenthal, who studies data storage at Stanford University in California, this kind of long-lasting medium is missing the point. He believes that we now live in an age where, if data isn't online, it may as well not exist. DOTS isn't designed to be searchable and easy to access, and for Rosenthal, that's a problem.

Rosenthal is working on a way to preserve society's data by networking many copies of it together. When one copy goes down, due to disc failure, human error or sabotage, the network can replenish that copy from another location. The idea is much like how Google backs up its data, but at a national level. One of the first such national digital archive networks is being built in the UK. Known as SafeNet, it will ensure that the knowledge accumulated digitally by UK universities perseveres. "If those copies get lost or damaged, they can be replaced," he says. SafeNet is due to go into service next year.

Relying on electronic data storage has a disadvantage when it comes to post-apocalyptic scenarios, or archaeological ones. One problem with recovering data stored electronically is that fragments aren't useful. Unlike books or DOTS, you either have the whole hard drive or you have nothing.

Even with the best efforts of people like Scott, Hummel and Rosenthal, a struggle to preserve every last tweet, blog post and Instagram is futile. The data that underpins our digital lives is subject to the same laws of thermodynamics that ensure a broken glass won't spontaneously reassemble. "I have long ago stopped disrespecting entropy," says Scott. "Life's capacity to break things down and take things away. It's ubiquitous, it's part of life." ■

ONE PER CENT



Tweeting rich

Tweets can be a sign of what's in your wallet. Researchers at the University of Pennsylvania studied thousands of Twitter accounts for differences between low and high-income users, using job titles disclosed in people's profiles as a proxy for income. High earners tended to discuss news and politics, while those with lower incomes preferred to chat among themselves (*PLOS One*, doi.org/742).

"Don't be evil"

Google's famous corporate guideline vanished from its code of conduct last week, as the company officially adopted its new name, Alphabet

Strong like... noodles

Building artificial muscle is hard, but Chinese researchers have found inspiration in a national dish – noodles. The key difficulty is persuading cells to develop into muscle tissue, as they only do this when subjected to a force that stretches and squeezes them. Yuhui Li at Xi'an Jiaotong University and colleagues made noodle-like fibres by extruding hydrogel through a sieve, then coated these with muscle cells. They used magnetism to expand and contract the fibres, so inducing muscle formation (*Advanced Functional Materials*, doi.org/f3ggzb).

INSIGHT Voice control

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Listen very carefully

OK computer, who am I?

What happens when phones know your voice, asks **Aviva Rutkin**

NOW your phone knows you better than ever. The latest version of Apple's mobile operating system learns what your voice sounds like, and can identify you when you speak to Siri, ignoring other voices that try to butt in.

Siri, the intelligent personal assistant, is not the only one who knows your voice. As learning software improves, voice-identification systems have started to creep into everyday life, from smartphones to police stations to bank call centres. More are probably on the way. In a paper published at the end of September, researchers at Google unveiled an artificial neural network that could verify the identity of a speaker saying "OK Google" with an error rate of 2 per cent.

Voice is a "physiological phenomenon" shaped by your physical characteristics and the languages you speak, says Roger Moore at the University of Sheffield in the UK. A passphrase such as "Hey Siri" or "OK Google" is a powerful way to verify that you are who you say you are, he adds.

"My voice is different from your voice, which is different from your mother's voice, which is different from someone on the far side of the world," Moore says. "The latest machine-

learning techniques can tease apart the tiny differences."

For machines, recognising individual voices is different from understanding what they are saying. The recognition software has been fuelled by massive sets of vocal data built into a huge model of how people speak. This allows measurements of how much

"Your voice doesn't just give away who you are, but what you're like and what you're doing"

a person's voice deviates from that of the overall population, which is the key to verifying a person's identity. Changes to someone's voice due to sickness or stress can throw off the software.

The technology is already being used in criminal investigations. Last year, when journalist James Foley was beheaded, apparently by ISIS, police used it to compare the killer's voice with that of a list of possible suspects. And the banks JP Morgan and Wells Fargo have reportedly started using voice biometrics to figure out whether people calling their helplines are scam artists.

Your voice doesn't just give away

who you are, but what you're like and what you're doing, says Rita Singh at Carnegie Mellon University in Pittsburgh, Pennsylvania. "Your speech is like your fingerprints or your DNA."

Singh is figuring out how to build profiles of a stranger from audio recordings. A voiceprint gives insight into the speaker's height and weight, their demographic background, and even what their environment is like. She is working with doctors in Massachusetts and Ohio to detect a person's likely diseases or psychological state through voice analysis.

Having devices in the home that recognise voices does raise security concerns, especially if they understand what you're saying. Speech and voice algorithms often aren't embedded in the device itself; instead, what you say is sent to a server somewhere else for analysis, and then ported back quickly. For example, Samsung fell into hot water this year with the revelation that its smart TVs could record private conversations.

"There are privacy concerns everywhere," says Singh. "There is no device out there that ensures privacy." ■

Curious bot roves ocean to find the new and unusual

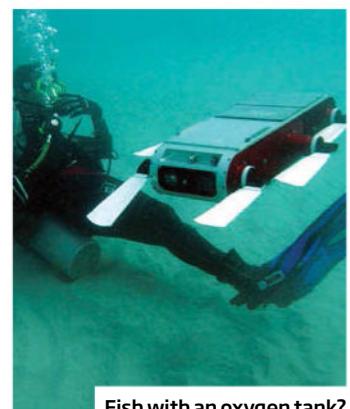
MOST of the ocean is empty, but it's also home to sharks, shipwrecks and strange undersea creatures. How's a robot to find the good stuff?

Yogesh Girdhar of the Woods Hole Oceanographic Institution in Massachusetts is giving bots a sense of curiosity. He wants them to be able to filter out common features, and focus on the remarkable.

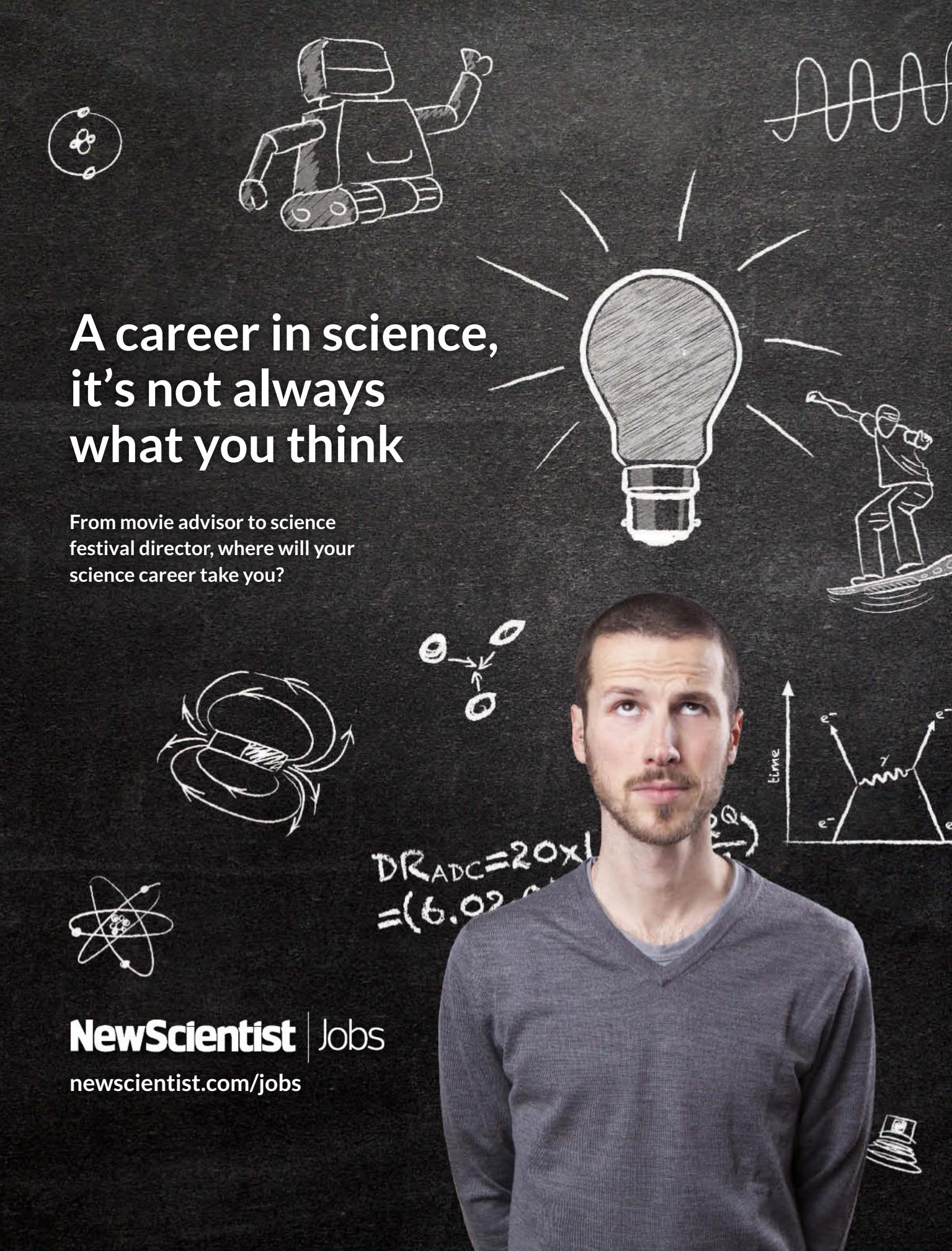
Girdhar's curiosity software (*Autonomous Robots*, doi.org/744) starts running as soon as a robot is dropped into a new place. It starts with little information about how the world looks, but slowly makes sense of what it sees by searching for patterns in the data. In the ocean, these come from things such as sand, kelp or fish.

The robot learns while it travels, watching out for things that don't quite belong. That mysterious stuff is automatically tagged as the most interesting, piquing the machine's curiosity and causing it to head over to take a closer look. In tests, a flippered robot called AQUA looked "like a puppy", racing and eagerly sniffing at new or unusual sights, says Girdhar.

"Having robots go out and make decisions on their own is a really important emerging area of research," says Nicholas Nidzieko at the University of Maryland. "Giving something a curious nature is another flavour of that." Aviva Rutkin ■

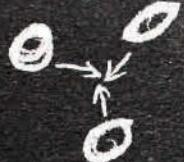
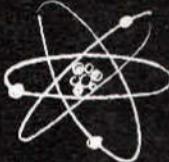


Fish with an oxygen tank?

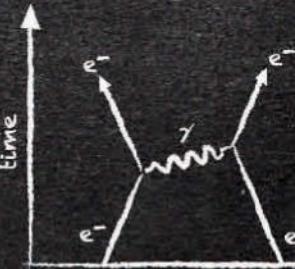


A career in science, it's not always what you think

From movie advisor to science festival director, where will your science career take you?



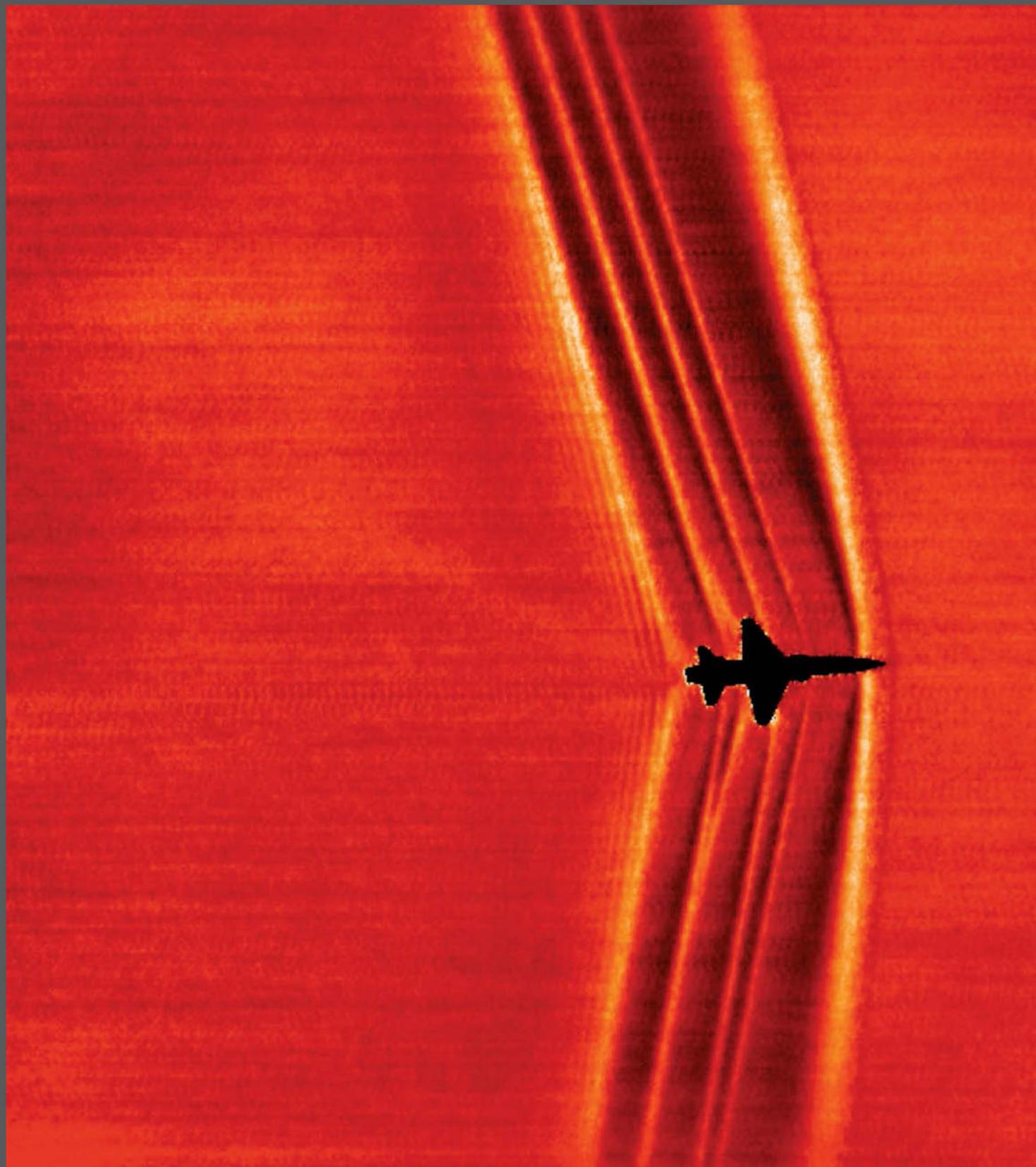
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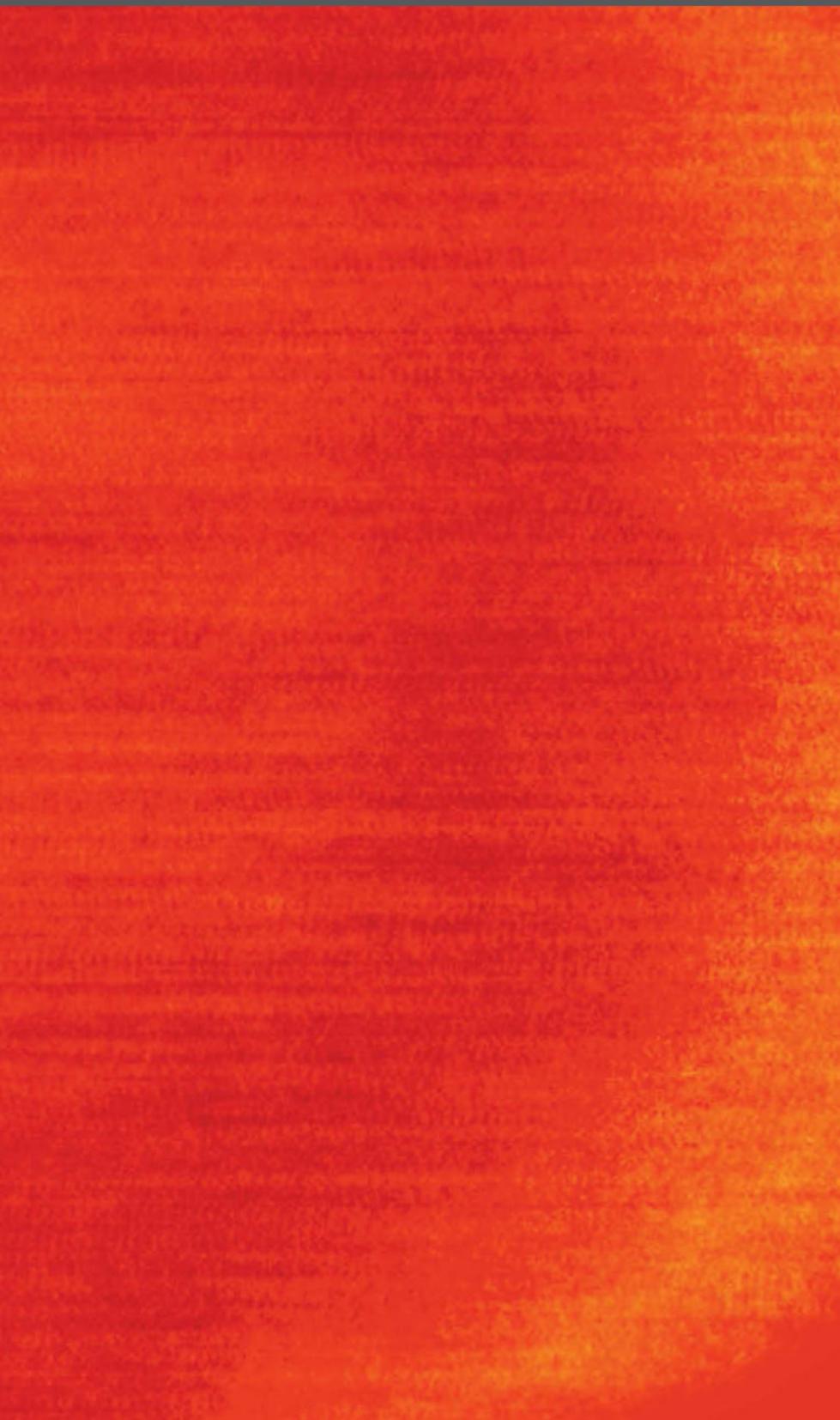


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APERTURE





Shock wave silhouette

IT'S like threading a needle while travelling faster than the speed of sound. Pilots at the US air force test pilot school flew this supersonic T-38C jet to the right place at the right time so that NASA could capture this photograph of the jet's shock waves. When the waves are forced together, they merge into one, creating a sonic boom.

This is the first time shock waves have been photographed from the ground in such detail. The technique takes advantage of the sun both as a very bright light source and as a background. Edward Haering at NASA's Armstrong Flight Research Center in California and his team used a special optical filter to reveal the sun's textured surface, stippled with sunspots (below). This meant the team could make hundreds of detailed observations of each shock wave by observing how it distorted the pattern of sunspots.

Skilful flying was needed to get the photo: the jet had to be within 90 metres of a specific point in the sky between the camera and the sun in a 2 minute window. Had it missed, the sun's position in the sky would have changed because of Earth's rotation and the opportunity would have gone.

The technique is called Background-Oriented Schlieren using Celestial Objects. Schlieren photography (from the German for "streak") was developed in the 1860s to visualise air flow around a moving object. The new method could also be used to take photos silhouetted against the pocked surface of the moon. Anna Nowogrodzki



Photography

NASA

Here comes Plan C

Even if deals made at climate talks in Paris aren't enough to keep global warming below 2 °C, all is not lost, says **Tim Flannery**

CRUCIAL climate talks in Paris are fast approaching, hailed as the last chance for a deal to avert dangerous warming. The good news is that the talks are already a success, in the sense that national pledges on emission reductions would change our current worst-case trajectory – we'd go from expecting a 4 °C increase by 2100 to being on track for closer to 3 °C.

The bad news is that the pledges won't avoid 2 °C of warming, the point where dangerous climate shifts loom large. Existing greenhouse gas concentrations commit us to a 1.5 °C rise, and the size of the changes needed to decarbonise the global economy makes it look inevitable that we will breach 2 °C this century.

And yet I remain hopeful. Why? Because we aren't factoring in what I call third-way technologies. These can reinforce Earth's natural system of self-regulation



by drawing greenhouse gases out of the atmosphere on a grand scale. They are distinct from emissions cuts – the first way of tackling climate change. And they should not be confused with second-way geoengineering – ideas such as pumping sulphur into the stratosphere to cool Earth, but which risk side effects like harming the ozone layer.

The third way encompasses biological and chemical routes to sequestering carbon. Biological paths involve photosynthesis, and include biochar creation, altered regimes of agricultural grazing and burning of tropical savannah, reafforestation and seaweed farming. One study indicates that if 9 per cent of the oceans were used for seaweed farms, the equivalent of all annual human carbon emissions could be captured, and the protein would be sufficient to feed the world.

Seen to be green

The VW scandal shows we need better ways to vet environmental claims, says **Fred Pearce**

COMPANIES increasingly make a great play of green credentials to attract environmentally friendly consumers. Much is promised, but how much is delivered?

Volkswagen is a case in point. In 2013, talking up issues including the environment, it said, "acting responsibly has always been part of our corporate culture... Anyone

wishing to check whether and to what extent we achieve this should first look at our products."

And someone did just that. The discovery of software used to rig emissions testing displayed the depth of willingness to cheat, even with something relatively easy to check, such as car fumes.

So what hope for less testable

business pledges on land grabs, deforestation, health, biodiversity and resources? How can we believe the promise of "zero deforestation by 2030" from big paper firms? Or Coca-Cola's "water neutral" aim? Or Unilever's vow to halve environmental impact by 2020? Or Nestlé's pledge of no land grabs in its supply chain?

These may be sincere, but how can we – or they – ensure they are kept? After the Volkswagen scandal, government regulators

"Environmental pledges by big business may be sincere, but how can we ensure they are kept?"

took a hit with revelations that repeated warnings of unreliable testing regimes for car emissions were ignored for years. Corporate self-policing, with some backing from environmental groups, is one option, but such efforts have led to criticisms that big-business interests still dominate.

If governments and self-policing aren't up to the job, what is? In the case of VW, the whistle was blown by an independent non-profit organisation. A few firms are actively opening their doors to similar bodies.

Unilever got independent researchers at the World Resources Institute to track deforestation in

Chemical pathways are diverse, including carbon negative concretes, the use of serpentinite rocks – which absorb CO₂ as they weather – manufacture of plastics and carbon fibres from CO₂ and the use of clean energy to convert CO₂ to hydrocarbons. Combined with a fresh look at carbon capture and storage, which involves locking the gas away long term, the third way offers a potent tool in efforts to stabilise the climate.

Today, all such technologies are immature or at the concept stage. For example, only 1000 tonnes of biochar are produced a year. Some of these methods sound like science fiction.

But 2050 is as distant from now as 1915 was from nuclear 1950. At a conservative estimate, by 2050 the third way could be drawing away the equivalent of 40 per cent of current emissions, close to what would lower CO₂ concentrations by 1 part per million a year. If this is to happen, we need to start large scale R&D now.

And while there may be a moral hazard in potentially diverting attention from the urgent task of reducing emissions, there is also one in neglecting the third way. ■

Tim Flannery heads the independent Climate Council in Australia. His latest book is *Atmosphere of Hope* (Penguin)

areas where it sources agricultural commodities. Trade giants Cargill and Wilmar got The Forest Trust to help them meet pledges.

We need more of this. It is clear that when CEOs make green vows or agree to government testing, that is just the start. External independent audits are essential.

At least we now know that the careers of business leaders – as well as the future of the planet – are on the line if environmental claims turn out to be hollow. More than anything else, that may concentrate minds. ■

Fred Pearce is a consultant for *New Scientist*

ONE MINUTE INTERVIEW

Pale blue dot's parting shot

We have a chance to update the message on the Voyager probes before they run out of juice. Let's take it, says **Christopher Riley**



PROFILE

Christopher Riley directed the BBC documentary *Voyager: To the final frontier*, and is author of *NASA Voyager 1 & 2 Owners' Workshop Manual* (Haynes). He is visiting professor of science and media at the University of Lincoln, UK

Why update the message on the Voyager probes, encoded in the Golden Record?

As humans we all connect with the Voyager Golden Record, which documents life and culture on Earth. When writing my book on the probes, I went through its contents: the pictures, the voices, the music. It struck me that many of the pictures were caught in a time capsule, capturing the struggles we were going through in the 1970s, such as coming to terms with the need to live more sustainably. Four decades on, with double the global population and many of those issues still prominent, I thought it was time to update the Golden Record with a little postscript.

How would you go about it?

There is no way you can touch what is on the Golden Record, and I wouldn't want to. That is a sacred time capsule. But the computer memory on the probes – something like 8 kilobytes on the main command computer – is full of operating code that just keeps it in housekeeping mode, looping the few experiments that are still running

and sending updates back. As the instruments fail, you could use some of that memory to store an update. The bandwidth on the probes is down to 40 bits per second. It would take just over 3 minutes to transmit a 1-kilobyte message, but that would be enough to send a 1000-character portrait of how society has changed in 40 years. That's about the size of seven tweets.

Have you written such a portrait?

I suggest a message in the book about population, about becoming more digital and interconnected – and the challenges and benefits of that. It sums up for me, slightly pessimistically, where we are today, 40 years after the Golden Record was made.

Have you talked to NASA about this?

Well, I've talked to the veteran engineers and they think it would be possible. We'll have contact with the probes until about 2023 and enough power on board to write such a message to their memory banks. As far as engaging with NASA goes, I figured that was best done through a public debate. But when you've got the chance to talk for the last time to craft that are going to outlive the Earth, why wouldn't you?

Will anyone, or anything, ever read it?

The odds are against that, given the vastness of where the Voyagers are going. Planetary scientist Jim Bell has proposed using any remaining fuel to do big engine burns that would bend the trajectories of the probes towards more populated parts of interstellar space, where the chances of passing within light years of a potentially inhabited planet go up. Will they be found? Probably not. But the team that put the Golden Record together didn't do it because of what it would say to aliens, but because it forced us to consider what we would say about our civilisation. The update is a tiny version of that exercise.

Interview by Sumit Paul-Choudhury

To win one of five copies of *NASA Voyager 1 & 2 Owners' Workshop Manual*, enter our competition at bit.ly/VoyagerManual

Try my extrasensory jacket on for size

Your reality need not be constrained by your biology. Wearable feedback can expand your perceptions, says **David Eagleman**

You have described the brain as "locked in a vault of silence and darkness", so how does it create such a rich reality for us to experience? That's one of the great mysteries of neuroscience: how do electrochemical messages in your brain get turned into your subjective experience of the world? What we know is that the brain is good at extracting patterns from our environment and assigning meaning to them. I'm interested in how we can plug alternative patterns into the brain and experience additional aspects of reality.

What new realities could we perceive?

We only pick up on a small fraction of signals that are going on in the world: those for which we have developed specialised sensors. There are many other signals out there – X-rays and gamma rays among others – but we're completely blind to them. No matter how hard we try, we'll never see that part of the spectrum naturally.

But the brain is really flexible about what it can incorporate into its reality. It receives information in the form of electrochemical signals from our eyes, our nose, our skin, and works out meaning from them. Crucially, it doesn't care where these signals are coming from; it just figures out how to use them.

I think of the brain as a general-purpose computer. Our senses are just plug-and-play devices that we have inherited through evolution. And if that's the case, we should be able to interface any data stream into the brain and it will figure out how to deal with it.

So how do you plan to patch a new data source into the brain?

We're experimenting with what we call the versatile extrasensory transducer, or VEST. It's a wearable device covered with vibratory

motors (pictured overleaf). When you wear the VEST, at first it just feels like strange patterns of vibrations on your torso, but the brain is really good at unlocking sensory patterns and figuring out what the input means.

How does a vibrating jacket allow us to experience a different reality?

Well, for example, we are trialling it with deaf participants at the moment. We capture sound from their environment and translate it into different patterns of vibrations. After a week or so our volunteers are able to figure out what's being said using the vibrations alone. They can understand the auditory world through their skin.

Do these people actually start experiencing hearing in the same way non-deaf people do?

That's a question we're working on right now. My expectation is that after many months of using the VEST, people who are deaf will have a direct perceptual experience of hearing that is the equivalent of how you or I hear.

We don't know if it will be exactly the same experience – it's hard to communicate what a sense feels like, because our language is only capable of sharing things that we have in common. Nonetheless, the meaning of what someone is saying is directly evident to the deaf participant. It might be like learning a foreign language – at first you read it and translate it in your head to get the meaning, but with practice you just read it and understand the meaning directly.

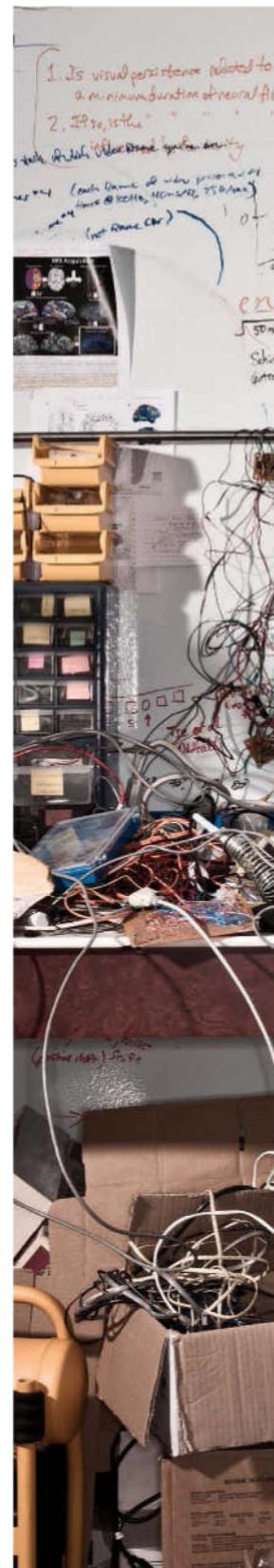
But the brain is specialised to hear different frequencies. Can it really figure out speech from vibrations on the skin?

It seems crazy to hear via a moving pattern of touch on the skin, but ultimately, this is just

PROFILE

David Eagleman is a neuroscientist and director of the Laboratory for Perception and Action at Baylor College of Medicine in Houston, Texas. His new book, *The Brain: The story of you* (Pantheon/Canongate), is published this month

We can sense things we are blind to, simply by interfacing the data into the brain





translated into electrochemical signals coursing round the brain – which is all that regular hearing ever is. Traditionally, these signals come via the auditory nerve, but here they come via nerves in the skin.

We already know that the brain can figure out meaning from arbitrary signals. For example, when a blind person passes their fingers over Braille the meaning is directly evident to them. And when you read words in a *New Scientist* article, you don't have to think about the details of the squiggles – the meaning simply flows off the page. In the same way, we're demonstrating that a deaf person can extract the meaning of words coming to them by vibratory patterns.

What else might we sense using the VEST?

Here's an example we're working on now. We stream 5 seconds of real-time data from the internet to a person wearing the VEST. Then two buttons appear on a screen, and the person has to make choice. A second later they get a smiley face or frowny face telling them whether their choice was the right one. The person has no idea that what they're feeling is real-time stock market data, and that the buttons represent buy or sell decisions.

"Our senses are just plug-and-play devices inherited through evolution"

What could this experiment demonstrate?

We're seeing whether participants get better at making trade decisions without having any idea what they are doing. People often come with a lot of assumptions about the market, and we want to see whether we can circumvent that by having the brain decrypt patterns without any pollution from prior knowledge. Then it's simply a pattern-recognition problem for the brain. Eventually we'll tell the participants what is really going on, and we are interested to know what the experience will be like for a person who wears this stock market VEST for long time. Are they suddenly going to feel a tightening in their stomach and think, "Oh gosh, the oil price is about to crash"?

Would they be able to describe in words what the different patterns meant to them?

Historically, people can figure out meaning from quite subtle data without ever knowing exactly what they're doing. Take British plane-spotters for example. During the second world war, some were really good at distinguishing between British and

German planes from a distance. The British government tried to get them to teach others to do it, but they were unable to. It was ineffable knowledge – they were picking out very subtle patterns without knowing exactly how.

The vibrating jacket has so many potential applications. What else have you in mind? Yes, it's hard to decide which possibilities to test first. We are playing with feeding the jacket a real-time sentiment analysis on Twitter, as filtered by a hashtag. Let's say you're a presidential candidate giving a speech. You could wear the jacket and feel how the Twittersphere is reacting as you're going along. One of our other experiments involves working with pilots and feeding them cockpit data or drone information via the VEST.

That's intriguing. Do the pilots end up feeling like they've become the drone, say?

Yes, it's like extending your skin to the plane or drone, so you feel the pitch, yaw and roll. It's a new perceptual experience that we believe will allow someone to pilot better. We're thinking about astronauts too. They spend a lot of time looking at hundreds of monitors, so wouldn't it be great if they could directly feel the state of the space station and know when things were changing or shifting?

Our whole lives are spent looking at little screens. In my view it's better to experience the data rather than simply look at it.

Are there limits to how many extra senses you might acquire using wearables?

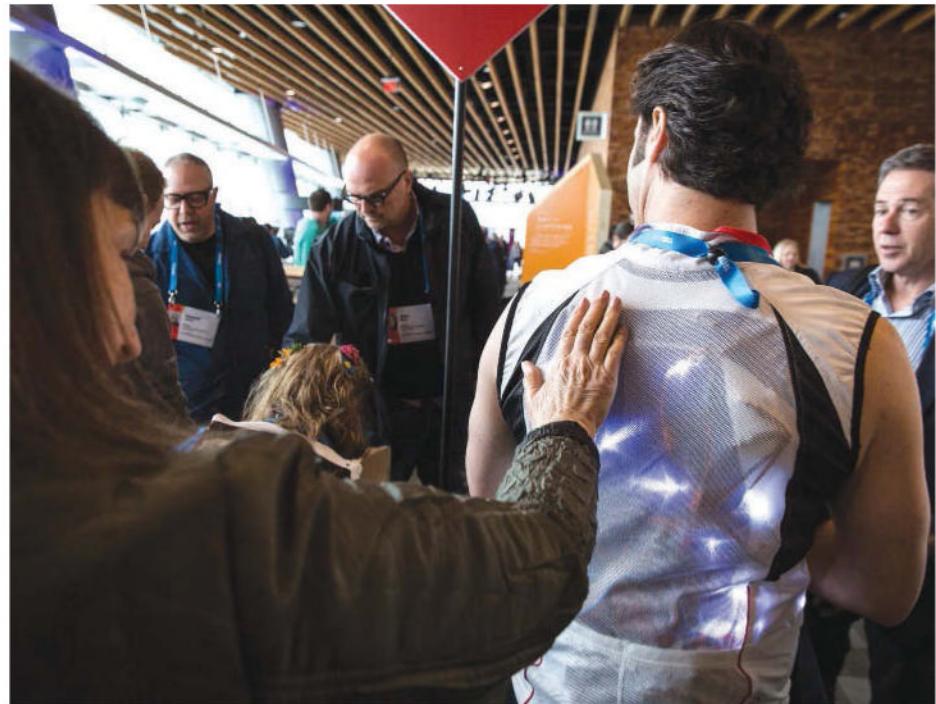
You mean, could you have a Twitter jacket and stock-market jeans? I don't see why not.

"A politician using the jacket could feel the Twittersphere reacting to a speech"

We don't know if there are any limits to how many different things you could sense. My intuition is that the limits are distant. We've got an enormous amount of real estate in the brain. If you lose one sense, the area of the brain responsible for it gets taken over by other senses. The brain is great at redistributing space for what's needed and there's plenty of room to share real estate without noticing any diminished effects elsewhere.

Does the VEST system have limitations?

The thing that defines what is possible is what we can build sensors for. If we have a good



JAMES DUNCAN DAVIDSON/TED

Touch and go: could this VEST give you a sixth and even a seventh sense?

sensor, it's trivial to convert the information it captures into vibrations in the jacket.

Could this technology could help us monitor our health?

That's a good example of waiting for the right sensors to come along. If you want to measure blood glucose you currently do it with a spot of blood, but now people are starting to develop sensors that can image glucose through the skin. When we have this sensor, it'll be easy for us to use it to feed data to the VEST. Then you'd have a direct way of experiencing your blood sugar level.

It's like when you sit still for too long in one position and then shift your body to get blood flowing to where it needs to go: you do that subconsciously using a stream of information from your muscles. It would be the same thing with the VEST. You're taking something that is normally invisible and making it visible. You would directly experience blood sugar readings and think, "I need to eat".

You mentioned in a recent TED talk that you might be able to give us 360-degree vision. How would that work?

I'm keeping that one under wraps for now, but the basic idea is that you'd wear a 360-degree camera and translate the data from that into

the VEST. My intuition is that it wouldn't end up feeling like vision – it would be more like a sixth sense, like "I can feel someone coming up behind me".

If you could choose only one extra sense to have, what would it be?

That's an interesting question. Right now, everything about our society is engineered around the senses that we currently have. If I were suddenly able to have ultrasonic hearing, I would hear animal calls that no one else could hear. As a nature lover that would be amazing, but I don't know if it would be lonely in that extrasensory space if no other human joins me there.

I'd also like to explore whether the VEST can allow us to better connect with other people. Perhaps if my wife and I both wore a VEST, and used it to somehow experience each other's emotions, that might bring us to a new level of closeness. Or perhaps it would be detrimental [laughs] – we just don't know until we try.

When can I buy one of these things?

In about nine months. We're working with engineers and fashion designers, and making everything open source so that anyone can input whatever data stream they like. We anticipate that the world's hive mind will come up with some great ways to use it. ■

Interview by Helen Thomson

SPECIAL ISSUE

GENERAL RELATIVITY AT 100

EINSTEIN'S
UNFINISHED
MASTERPIECE

WHAT WE KNOW - WHAT WE DON'T - WHAT COMES NEXT

RELATIVELY SUCCESSFUL

Einstein's general theory of relativity is an undoubtedly work of genius. Yet 100 years on, it still raises many questions – and physicists continue to look for something better

ALBERT EINSTEIN'S contributions to modern physics are unmatched, but his stellar reputation rests above all on a theory he presented to the Prussian Academy of Sciences in Berlin in a series of lectures in November 1915. The general theory of relativity is at its heart a theory of gravity. But in explaining how the force that sculpts large-scale reality works, it revolutionised our world view.

Ten years before, in 1905, Einstein had already shown how motion warps space and time. Starting with the assumption baked into James Clerk Maxwell's theory of the electromagnetic force, formulated 40 years earlier, that light always travels at the same speed, the special theory of relativity demonstrated how two observers in motion relative to each other will not perceive ruler lengths and clock ticks the same way.

For the general theory, Einstein combined this with another observation: that gravity's effects on a body with mass cannot be distinguished from the effects of an acceleration. After a decade of calculation, he reached his conclusion: gravity is a product of warped space-time. The sun keeps Earth in orbit not by exerting a physical force on it, but because its mass distorts the surrounding space and forces Earth to move that way. In the words of physicist John Archibald Wheeler, "space tells matter how to move and matter tells space how to curve".

A PERFECT THEORY?

Observations led by the British astronomer Arthur Eddington during a solar eclipse in 1919 showed how the sun's bulk bent the light reaching Earth from distant stars, just as the new theory predicted. In the past

century, general relativity has never failed an experimental test, and has become the foundation of a new picture of an expanding universe that began in a big bang 13.8 billion years ago (page 31).

Yet for all its success, general relativity makes many physicists uneasy. Its prediction of black holes, monsters that suck in everything they come into contact with, is a perennial cause of discomfort – even though these bodies do seem to exist (page 34). The theory's incompatibility with quantum theory, which explains how all the other forces of nature work, including electromagnetism, remains a problem (page 37). Then there is our failure so far to directly detect gravitational waves, ripples in space-time that are an essential prediction of the theory (page 40).

It is time, after a century, to look back – and ask what the next century might bring.



EINSTEIN'S WITNESS

General relativity's story of the universe is writ large in the sky, says physicist **Pedro Ferreira**

A FEW years ago, I was interviewing a cosmologist applying for a fellowship to study the cosmic microwave background. I asked her what she thought the great developments in the field would be over the next few years. Her answer: pretty much none; the big picture was more or less done and dusted.

It might seem like she was shooting herself in the foot. The accidental discovery 50 years ago of the CMB, the afterglow of the big bang, is perhaps the greatest triumph of our general-relativistic model of the universe. It was detected as an unexplained hiss in an antenna built for experiments on terrestrial microwave communication. Since then, studies of the CMB have provided convincing proof that our universe began in a hot, dense pinprick and has been expanding ever since, releasing this radiation when it had cooled sufficiently for the first atoms to form.

Studying the CMB has allowed us to characterise the universe's beginnings at energy scales unreachable by CERN's Large Hadron Collider particle accelerator, or any conceivable successor. Ground-based ➤

100 YEARS OF GENERAL RELATIVITY

In a century,
Einstein's theory has
revolutionised our picture
of the universe

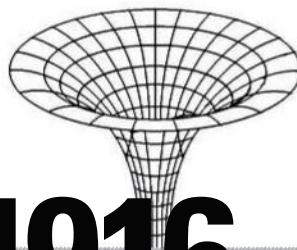
1915



Einstein presents his
**field equations of
general relativity** to the
Prussian Academy of
Sciences in Berlin

1916

Einstein uses general
relativity to predict the
existence of
gravitational waves,
ripples in space-time
produced when
massive bodies interact



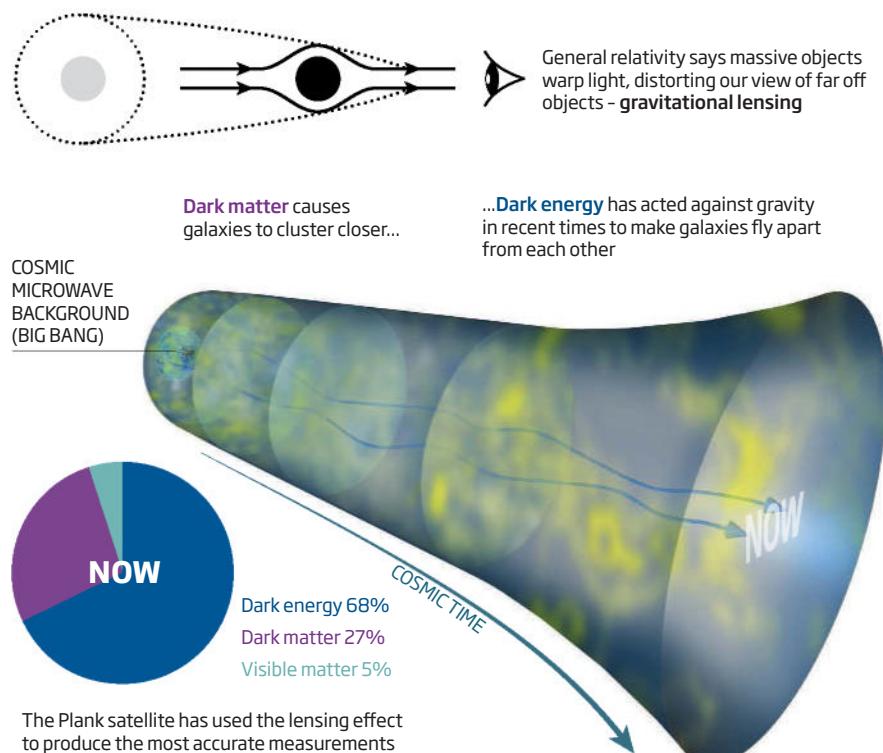
experiments, and latterly space missions such as the WMAP and Planck satellites, have used the radiation to measure the geometry of the universe with incredible precision and provide our best figure yet for its age – 13.8 billion years. They have also elucidated the astounding facts, first flagged in studies of galactic rotation and far-off supernovae, that the vast majority of cosmic stuff comes in forms that we cannot see: dark matter and dark energy.

Yet I liked the candidate's confidence, and she got the job. Although we expect to increase the accuracy of the measurements already made, and the mysteries of dark matter and energy remain, the big picture of the general-relativistic universe has indeed been fleshed out. Too many observations agree too well for it all to be a house of cards.

Comprehensive surveys of how galaxies are distributed that are now in the works will help fill in the gaps and shed light on how dark matter and energy have influenced the universe's evolution. But there is much detail still to be gleaned from the CMB itself. Our most compelling description of the early universe

Lens on the past

Photons from the cosmic microwave background left over from the big bang get distorted on their way to us. Measuring those distortions tells us how the balance of **dark matter** and **dark energy** has changed all the universe's life



1917

Einstein introduces an extra term into his equations, the **cosmological constant**, to balance out gravity and produce a static universe that is neither expanding nor contracting

FROM LEFT: AKG/DE AGOSTINI PICTURE LIB / AKG IMAGES, ROYAL ASTRONOMICAL SOCIETY/SPL



1919

Arthur Eddington observes the sun's mass bending light during an eclipse over the island of Principe - the **gravitational lensing** effect predicted by Einstein

says it underwent a period of accelerated expansion, known as inflation, that stretched microscopic quantum fluctuations of space-time out to astronomical scales. According to the precepts of general relativity, these events should have sent ripples out through space-time. Early in 2014, CMB measurements by the BICEP2 experiment at the South Pole seemed to have found these primordial gravitational waves – although under closer scrutiny, it turned out that the observed effect was caused by effects within our own galaxy. The search for gravitational waves continues in the CMB and elsewhere (see “The missing piece”, page 40).

Up till now, we have pored over the CMB rather as we would a picture of a distant ancestor, trying to discern the traits in it that led to what we see today. But it can also be a backlight to illuminate the present or, at least in cosmological terms, the very recent past – and so show up the subtleties of how gravity has shaped our universe.

Take the gravitational lensing of CMB light as it propagates towards us – the effect that Arthur Eddington used to provide the

first proof of general relativity in 1919 (see “100 years of general relativity”, above). CMB photons will be deflected by warps and folds in space-time caused by the large-scale distribution of matter in the universe, ever so slightly distorting our view. By tracking this effect over time, lensing measurements from the Planck satellite have confirmed that the universe’s expansion is indeed accelerating under the influence of dark energy.

Still more sensitive measurements of the distorted CMB should allow us to work backwards to the distribution of dark matter, which apparently makes up more than 80 per cent

of every galaxy. This gives us a new window on how the complex filaments, walls, clusters and voids of the “cosmic web” have formed over time, without having to worry about the messy details of normal matter’s interactions (see diagram, left).

THE BIGGEST TEST

Distortions introduced when photons from the CMB scatter off electrons in intervening galaxy clusters will also allow us to measure how fast these clusters are moving around, and how quickly they are collapsing gravitationally, sucked into denser forms through dark

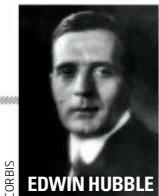
matter’s influence. That gives us a new way of testing general relativity’s predictions. For although the theory has been exquisitely studied on the scale of the solar system and in the orbits of neutron stars, it has yet to be tested on scales spanning billions of light years.

The safe bet is that general relativity correctly describes the universe out to cosmological scales, for all that we are baffled by the dark spectres it calls into life. If general relativity were ever proved wrong that would be a true revolution. It would call into question the existence of dark energy as the driving force behind the universe’s expansion in recent eras. But it would also force us to figure out what hallowed principles we need to jettison to obtain a description of gravity on cosmic scales that is different to the one we have been using for the past century. That is a question to which few people as yet have wagered an answer. ■

“If general relativity were ever proved wrong that would be a true revolution”

Pedro Ferreira is a cosmologist at the University of Oxford and author of *The Perfect Theory* (Abacus, 2015), an account of the past century of general relativity

1920s



CORBIS

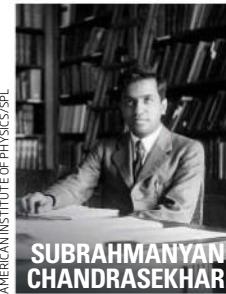
Alexander Friedmann and Georges Lemaître independently find a solution to Einstein's equations that describes a uniformly expanding universe

1920s

Edwin Hubble and others show far-off galaxies are moving away from us - the first hint of an expanding "big bang" universe. Einstein decries his cosmological constant as his "greatest blunder"

1930

Subrahmanyan Chandrasekhar shows that certain massive stars could collapse into bodies so dense that no light could escape from them: what later became known as black holes



AMERICAN INSTITUTE OF PHYSICS/SPL

SUBRAHMANYAN CHANDRASEKHAR

DARK DESTROYERS

Black holes are general relativity's most mind-bending prediction – and could yet swallow the theory, finds

Anil Ananthaswamy

IT WAS while serving in the German army on the Russian front that, in the winter of 1915-1916, the physicist Karl Schwarzschild sent Albert Einstein some papers. He had solved Einstein's equations of general relativity for the first time, and shown what happens to space-time inside and outside a massive object – in this case, a perfectly spherical, non-spinning star. Einstein was thrilled.

He wouldn't be so thrilled with a prediction that eventually emerged from Schwarzschild's work. Make a star compact enough and it could develop a gravitational pull so great, and warp space-time so much, that even light would not escape.

Just months after his exchange with Einstein, Schwarzschild was

dead. It was left to others to work through the details of these curious compact objects, the surfaces of which became known as Schwarzschild singularities.

Chief among them was a young Indian physicist named Subrahmanyan Chandrasekhar. In 1930 he boarded a steamer from India to the UK, where he was to take up a scholarship at the University of Cambridge. Whiling away the 18-day voyage, he worked on the properties of highly compact white-dwarf stars. He found that if they had more than 1.4 times the sun's mass, they would implode under their own gravity, forming a Schwarzschild singularity.

This did not go down well. At a meeting of the Royal Astronomical Society in 1935, the

eminent astrophysicist Arthur Eddington declared that "there should be a law of nature to prevent a star from behaving in this absurd way". In 1939, Einstein himself published a paper to explain why Schwarzschild singularities could not exist outside the minds of theorists.

The impasse remained until the 1960s, when physicists such as Roger Penrose proved that black holes – a term coined at about this time, probably by astrophysicist John Archibald Wheeler – were a seemingly inevitable consequence of the collapse of massive stars. At a black hole, physical quantities such as the curvature of space-time would become infinite, and the equations of general relativity would break down.

Not only that, but a black hole's interior would be permanently hidden behind its event horizon, the surface of no return for light. That in turn meant that nothing happening in the interior could influence events outside, because no matter or energy could escape. "The first major paradigm shift was the understanding that these solutions [of general relativity] are meaningful, and that there is a

notion called a horizon, and that it is a causal barrier separating the inside from the outside," says theorist Don Marolf of the University of California, Santa Barbara (UCSB).

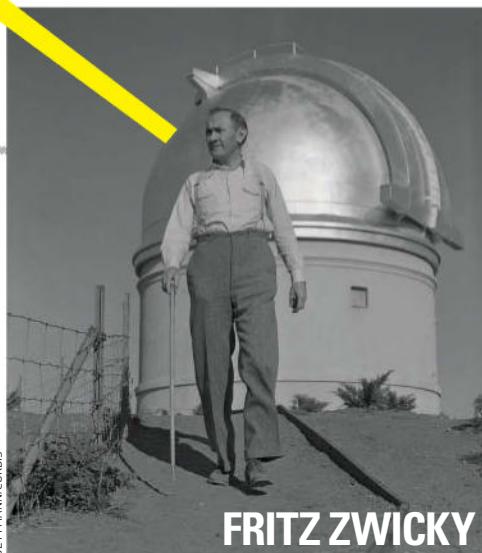
Although we can't see a black hole directly, in 1970 astronomers observing a compact object in the constellation Cygnus saw jets of X-rays consistent with theoretical predictions of radiation streaming from hot matter spiralling towards an event horizon. Since then, our appreciation of black holes' reality has only grown. It seems most galaxies, including our Milky Way, have a supermassive example lurking at their heart (see "Black hole paparazzo", page 36).

Yet the ins and outs of black holes remain hotly disputed – not least for what they say about general relativity's failure to mesh with quantum theory (see "Unhappy marriage", page 37). "You have to go to pretty extreme environments for both of these theories to be important at the same time, and a black hole turns out to be one of the most ideal," says theorist Joseph Polchinski, also at UCSB.

Tensions rose in the 1970s,

1933

Fritz Zwicky observes that galaxies in clusters are seemingly being whirled around by the gravity of invisible matter – the first hint of the existence of dark matter



FRITZ ZWICKY

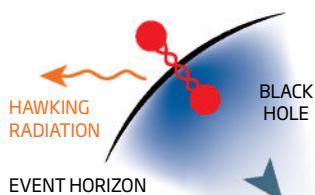
1940s

Theorists predict that if the universe is expanding from a hot and dense beginning in a big bang, it should have left behind an afterglow: the cosmic microwave background

The great firewall paradox

Pairs of quantum-entangled particles constantly pop into existence at a black hole's event horizon. What if one member of a pair falls in?

The entanglement encodes information, and that can't vanish, according to **quantum theory**. It might escape via photons of Hawking radiation, which black holes should emit...



when physicists Jacob Bekenstein and Stephen Hawking showed that black holes must have a temperature. Bodies with a temperature have an associated entropy, and in quantum mechanics, entropy – a measure of a body's disorder – implies the existence of a microstructure. Einstein's equations, meanwhile, describe black holes as smooth, featureless distortions of space-time. Hawking also showed that quantum effects in and around the event horizon imply the black hole should steadily evaporate, emitting a stream of what we now call Hawking radiation.

But if a black hole does eventually dwindle to nothing, what happens to the stuff that falls in? At a fundamental level, matter and energy carry some information, and quantum mechanics says information cannot be destroyed. Perhaps the information encoded slips out with the Hawking radiation, but this idea runs into another problem: it leads to the black hole being surrounded by a "firewall" of blazing, energetic particles, again something general relativity forbids. In 2012, Polchinski, Marolf and their colleagues showed that

black holes cannot simultaneously preserve information and possess an uneventful horizon (see diagram, left).

DISAPPEARING ACT

This "firewall paradox" is still a hot topic. One emerging and tantalising suggestion is that the smooth fabric of Einsteinian space-time results from particles inside and outside the event horizon being linked quantum mechanically, via structures known as wormholes.

In August, speaking at a meeting in Stockholm, Sweden, Hawking set out an alternative stall, suggesting that information is never actually swallowed by a black hole. Instead, it persists at its event horizon in a form that is garbled and hard to decode. Last month, Nobel laureate Gerard 't Hooft of Utrecht University in the Netherlands suggested that when matter and energy fall in, their information just bounces back.

Some sidestep such problems by returning to arguments reminiscent of Eddington's and Einstein's denial of black holes. Last year Laura Mersini-

Houghton of the University of North Carolina, Chapel Hill, argued that massive stars cannot collapse to black holes – the emission of Hawking radiation during the collapse stops the star ever getting that far. So there are no event horizons and no singularities.

Few subscribe to that view, not least because of the considerable indirect observational evidence for black holes. Instead, the firewall paradox has opened up a new front in the struggle to unite general relativity and quantum mechanics. In that tussle, there's a sense that the successful theory will be closer to quantum theory than general relativity, given the overwhelming success of quantum theory in explaining all the forces of nature besides gravity. Marolf, a general relativist, says he feels bad admitting that "general relativity is losing". Einstein, who was troubled both by black holes and what he saw as quantum theory's excesses, may have felt worse. Black holes could end up being the prediction that ate the theory. ■

Anil Ananthaswamy is a consultant for *New Scientist*



1964



The **cosmic microwave background** is accidentally discovered by Arno Penzias and John Wilson as unexplained noise in a radio antenna, kicking off relativity's "golden age"

1970s

Vera Rubin provides convincing evidence that most galaxies contain **dark matter**, which is causing them to rotate faster



E. SEGRE VISUAL ARCHIVES/ALAMY SPL

1972

X-ray emissions from a body known as X-1 in the constellation Cygnus provide the first evidence for a star's collapse into a **stellar-mass black hole**

BLACK HOLE PAPARAZZO

Astronomer **Heino Falcke** plans to use a global network of radio telescopes to snap the black hole at the Milky Way's heart

Why photograph a black hole?

Black holes were predicted a century ago, but I have the feeling that we understand them even less these days. We still don't have conclusive evidence for the presence of an event horizon - their point-of-no-return surface. Also, event horizons and quantum theory just don't go together. Something needs to change, and it's not entirely clear what that is.

How do we even know there's a black hole in the Milky Way's core?

Stars in the galactic centre orbit at some 10,000 kilometres per second, meaning there must be a central mass that is more than 4 million times our sun's mass. The only thing that we "see" in the very centre is a radio source called Sagittarius A*. Its very short, sub-millimetre radio waves probably arise from jets of hot gas

emitted by material plunging into a supermassive black hole.

How will your planned giant network of radio telescopes help?

The black hole's event horizon is probably 25 million kilometres across, but it's 27,000 light-years away. To image it at sub-millimetre wavelengths you need a telescope as big as Earth. A worldwide network of radio telescopes can obtain the same resolution.

Aren't US astronomers working on a similar idea?

I first discussed these ideas 10 years ago with Shep Doeleman of the Massachusetts Institute of Technology, who now heads the US-led Event Horizon Telescope project. It makes no sense for us or them to work with a subset of the available telescopes, so we are now trying to set up a global project. We need each other.



Profile

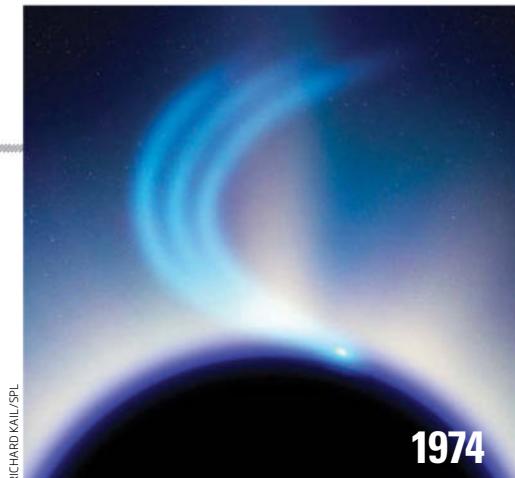
Heino Falcke is a radio astronomer and astroparticle physicist at Radboud University in Nijmegen, the Netherlands. In 2013, the BlackHoleCam team he co-founded received a €14 million grant from the European Research Council

Where are the telescopes you'll use?

The European groups are working with sub-millimetre telescopes in Spain, France and Chile. The US teams use telescopes in Hawaii, Arizona, Mexico and at the South Pole. Ideally, to increase the efficiency of the Earth-sized virtual telescope, we need a new instrument in Africa. I raised this idea

1974

Russell Hulse and Joseph Taylor discover a pair of neutron stars whose orbits are slowing exactly as if they were losing energy by emitting gravitational waves



1974

Stephen Hawking shows theoretically that quantum effects can cause black holes to evaporate, emitting Hawking radiation – posing the question of what happens to the matter they swallow

at a recent workshop; we hope to start a fundraising campaign later this year.

What exactly are you looking for?

We hope to see how radio waves from the black hole's surroundings are bent and absorbed, just as in Christopher Nolan's movie *Interstellar*. The result should be a sort of central "shadow". By comparing the size, shape and sharpness of this shadow with theoretical predictions, we can test general relativity. If the shadow is half as big – or twice as large as predicted, say, general relativity can't be correct.

What are the biggest challenges?

The technology is daunting, but now under control. For each telescope you have to record hours of data at a rate of 64 gigabits per second and ship hard discs with petabytes of data between continents. Budget issues have eased a little bit with grants from the European Research Council and the US National Science Foundation.

When will we have our first black hole portrait?

In 2000, I said a result might be in within a decade, so I'd better temper expectations a little bit. Will it be another 10 years? I hope not, but in the end it takes the time it takes. ■

Interview by Govert Schilling

General relativity: Deeper

For further reading, links to related *New Scientist* features and an interactive guide to Einstein's seminal field equation of general relativity, go to bit.ly/DeepRelativity

UNHAPPY MARRIAGE

General relativity and quantum theory don't agree. How so, asks physicist Eugene Lim – and what can we do about it?

ARATHER glib distinction is often made between the two pillars of modern physics. Quantum mechanics is the physics of the very small, while general relativity is the physics of the very large. That's not quite accurate – for example, quantum-mechanical effects have been observed spanning hundreds of kilometres. And at some scale, surely these two supremely accurate theories must come together.

Yet wherever they do cross paths, the two theories fail to play nicely together – such as around black holes (see "Dark destroyers", page 34). Efforts to establish a quantum theory of gravity have stumped many physicists over the past century. Einstein himself became extremely unproductive in his later years as he sought such a "theory of everything".

To understand why, we must

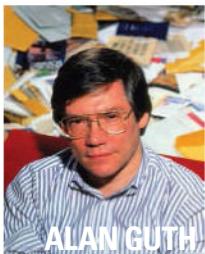
start with a fundamental tenet of quantum physics. Heisenberg's uncertainty principle embodies the fuzziness of the quantum world. It allows particles, such as electrons or photons of light, the equivalent of an interest-free loan: they may borrow energy from empty space and use it to make mass, according to Einstein's famous equation $E = mc^2$. This mass takes the form of short-lived "virtual" particles. The only caveat is they must pay this energy back – the particles must disappear once again – before anyone asks any questions. The more energy they borrow, the quicker this must happen.

Given such freedom, one can imagine an electron, photon or any other particle going to town, taking out many zero-interest loans in succession. As a result, calculating even a prosaic quantum process – an electron ➤

1980

Alan Guth and others propose the big-bang universe was smoothed out by undergoing a period of breakneck expansion in its first instants - **inflation**

DAVID PARKER/SPL



ALAN GUTH



1989

NASA launches COBE, a satellite to study the cosmic microwave background. It reveals a largely homogeneous radiation field, supporting the idea of an **inflationary big bang**

“Few people want to believe reality has no single consistent underpinning”

travelling from left to right, say – becomes enormously complex. In the words of physicist Richard Feynman, we must “sum over all possible histories”, taking into account the infinite variety of ways virtual particles can be produced (see diagram, right).

The history of applying quantum theory to nature’s forces is a history of getting to grips with these unruly infinities. One huge success story is electroweak theory, the theory that combines the electromagnetic and weak

nuclear forces to explain how electrons and photons work. Its predictions, of everything from particle masses to their decay rates, are accurate up to 10 decimal places.

The winding way to electroweak theory is marked by at least nine Nobel prizes. The eventually successful variant, a bedrock of today’s “standard model” of particle physics, tamed the mathematics using a bunch of undiscovered massive particles, the W, Z and Higgs bosons.

Fortune eventually favoured this brave conjecture: the W and Z bosons were discovered at CERN in 1983, with the Higgs following in 2012. The first of those successes, in particular, led many physicists to believe this strategy was something like a general prescription for developing quantum theories: if your model produced infinities, just add in extra particles of large mass to solve the problem.

Suppose, then, gravity is made of quantum particles called gravitons, much as light is made of photons. Following the uncertainty principle, gravitons borrow energy to make other, virtual gravitons. As we sum over all possible histories, the calculations rapidly spiral as expected into a chaos of infinities.

But this time, the fix doesn’t work. Eliminating these infinities requires inventing a second particle with a mass 10 billion billion times that of a proton. As ever, the larger the amount of energy borrowed, the more

quickly it must be paid back, so these fixer particles are very short-lived. This means they can’t get very far, and so occupy only a minute amount of space.

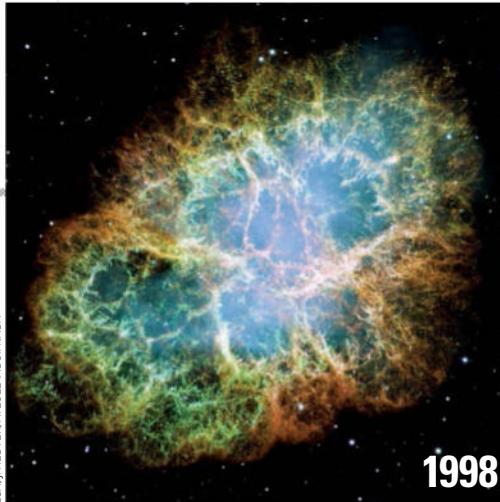
But general relativity says that mass bends space-time. Concentrate enough mass into a small area, and a black hole will form, a point of infinite curvature in space-time. And this is exactly the guise our new particle takes. Nature plays a cruel joke on us: our scheme to eliminate one sort of infinity creates another.

CHANGING THE GAME

Attempts to get round this fundamental roadblock have led us to destinations such as string theory, which assumes all particles are manifestations of more fundamental vibrating strings. When we start summing over all possible histories of these “fluffier” objects, the hard infinities produced by virtual particles drop away almost by

1998

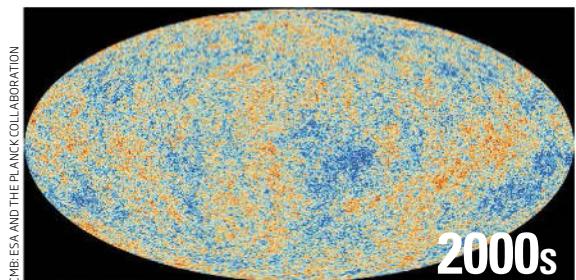
Studies of far-off supernovae surprisingly reveal that the universe's expansion is accelerating. Einstein's cosmological constant is revived as one identity for the dark energy causing this effect



ESA, J. HESTER, A. LOLOV (ASU/NASA)

2000s

Ever-more detailed studies of the cosmic microwave background support the picture of a cosmos that began in an inflationary big bang dominated by dark matter and dark energy

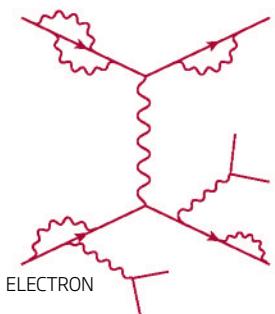


CMB: ESA AND THE PLANCK COLLABORATION

magic. Another commonly considered idea is loop quantum gravity, which suggests that space-time itself is chopped up into discrete blocks. This pixelation imposes an upper limit on the amount of energy any particle can borrow, again rendering calculations finite.

Infinite problem

Gravitons are conjectured quantum particles of gravity - but theories incorporating them tend to be unruly



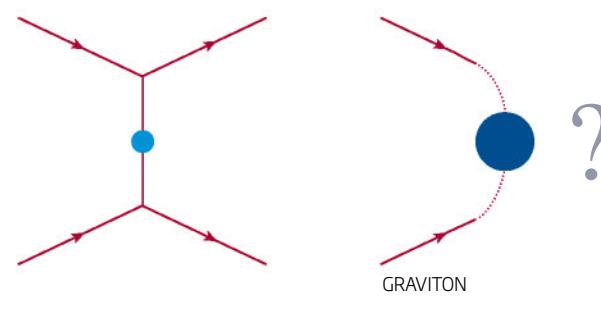
Particles such as electrons can interact by producing and exchanging massless photons in countless ways, often resulting in infinities in the calculations

Despite their seemingly radical assumptions, these two candidate unified theories are in many ways the most conservative extensions of current models: both attempt to preserve as much of the theoretical underpinnings of quantum mechanics and general relativity as possible.

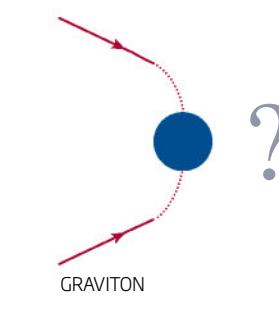
What about more esoteric ideas, such as changing the rules of the existing game? For instance, if general relativity were to treat space and time separately again, rather than lumping them into one combined space-time, that might provide some wiggle room. But relativity and quantum

mechanics both tally so well with reality in their respective spheres that it is devilishly difficult to formulate such tweaks. Few physicists would care to consider an even more radical possibility: that quantum mechanics and general relativity cannot be unified, and reality has no single, consistent logical underpinning.

In the first century of general relativity, all these considerations have been theoretical. But now technology is finally catching up. Despite liberal use of gravitons for calculations, we have yet to detect their existence directly. Gravitational-wave experiments such as Advanced LIGO in Louisiana and Washington state and the proposed eLISA spacecraft will hopefully close that gap (see "The missing piece", page 40) – and so perhaps lead us to a deeper understanding of how gravity really works. ■



The situation is saved by the existence of heavier particles – the **W, Z and Higgs bosons** that aren't so easily produced, cancelling out the infinities



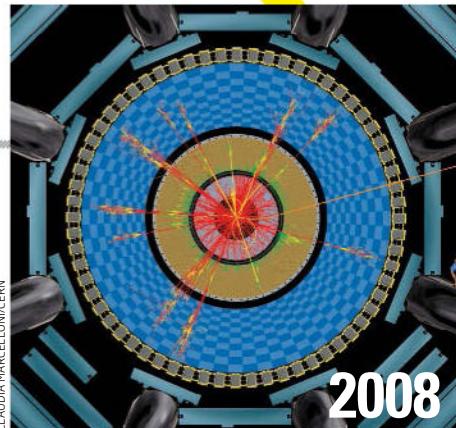
Performing the same trick with graviton interactions requires a particle so massive it acts like a **black hole** – and all calculations are off again

Eugene Lim is a theoretical physicist at King's College London



2003

The DAMA experiment under the Gran Sasso mountain in central Italy claims to have seen a signal of Earth ploughing through a sea of **dark matter** – but other experiments fail to verify it



CLAUDIA MARCELLONI/CERN

2008

THE MISSING PIECE

One prediction of general relativity remains unverified – gravitational waves. But what if we just can't find them, asks **Matthew Chalmers**

EINSTEIN was a prolific predictor of new phenomena, often relying on ingenious thought experiments to turn reality on its head. Almost as often, he had difficulty coming to terms with the results.

Gravitational waves are a case in point. And although Einstein eventually accepted that these oscillations in space-time could exist, they remain the only major prediction of general relativity still to be verified. The latest and best detector dedicated to finding them has just come online. If nothing's there, something is deeply awry. "It would be absolutely mystifying," says Alessandra Buonanno of the Max Planck Institute for Gravitational Physics in Potsdam, Germany. "We cannot not see them."

Matter causes space-time to curve, says general relativity. When a large mass accelerates, that curvature should change. The result is ripples in space-time that spread out at the speed of light, just as electromagnetic waves generated by accelerating electric charges spread.

Except not quite: rather than propagating through space-time as electromagnetic waves do, gravitational waves are contractions and expansions of space-time itself. Because gravity is much weaker than electromagnetism, they are also minuscule by comparison.

All of that makes calculations with gravitational waves rather hairy. Einstein realised straight away that the equations of general relativity had wave-like solutions, and in 1918 he derived a

formula that allowed him to estimate how much energy these waves should carry. But he regarded the waves as unphysical, and general relativity's core equations are so intractable that controversy persisted for decades over whether the formula was even theoretically sound.

Even if sound, the formula suggested that only the most massive objects in the universe could produce a detectable signal: two black holes or neutron stars in a tango, for example. A typical gravitational wave would distort surrounding objects by less than one part in a billion trillion as it passed through Earth. Detecting such small displacements is akin to measuring the distance between Earth and the sun to the accuracy of an atomic radius.

WAVE HELLO

It was only after Einstein's death that gravitational waves became widely accepted. Experimentalists duly built detectors, initially large suspended cylinders that might be nudged by a passing wave. In the late 1960s, US physicist Joseph Weber was the first to claim a sighting. More than a dozen such

claims followed, but none stood up to scrutiny.

To a theorist such as Buonanno, our failure to detect gravitational waves directly is academic: we already have overwhelming indirect proof that they exist. In 1974, astronomers Russell Hulse and Joseph Taylor discovered a binary pulsar – an orbiting pair of neutron stars beaming out radio waves at precise intervals – and started tracking its rotation rate. By the early 1990s they had shown that the stars were losing energy at precisely the rate Einstein predicted they would if they were emitting gravitational waves. A handful of similar binary systems studied since then have confirmed this view.

The observations could just be spurious: perhaps some strange astrophysical process is tricking us into thinking the binaries are slowing down, says theorist B. S. Sathyaprakash of Cardiff University in the UK. Or perhaps gravitational waves are being emitted as predicted, but aren't reaching us. But in this case, "it is not easy to come up with a theory that does one thing and not the other", says Sathyaprakash.

2008

The Large Hadron Collider fires up at CERN near Geneva, Switzerland. One of its aims is to make **dark matter** particles



STEFFEN RICHTER/HARVARD UNIVERSITY

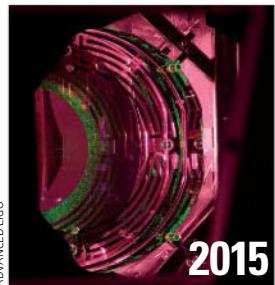
2014

Physicists working with the BICEP2 telescope at the South Pole claim to have seen the imprint of primordial **gravitational waves** on the cosmic microwave background – a claim later retracted

2014

2015

Advanced LIGO is the latest attempt to observe **gravitational waves** directly



ADVANCED LIGO

The search for alternative proof continues. Pulsar timing arrays are one relatively new method. They chart the precise arrival times of radio waves from a series of fast-rotating binaries. If space-time momentarily wobbles, we ought to see a distinctive radio pattern – one now being hunted by the International Pulsar Timing Array, a global network of radio telescopes.

The Advanced Laser Interferometer Gravitational-Wave Observatory (Advanced LIGO), which turned on last month after a five-year upgrade of a previous detector, uses a more direct method. It bounces laser beams up and down detector arms that are kilometres long to spy distortions caused by passing gravitational waves. Its detectors in Louisiana and Washington state will work in sync with instruments in Germany (GEO600), Italy (VIRGO) and Japan (KAGRA).

Advanced LIGO is 10 times more sensitive than the detector it replaces, and can scan a volume of space more than a thousand times bigger. That means we're now almost certain to strike success, believes James Hough of the

University of Glasgow, UK: "I personally believe the advanced detectors will make a discovery."

But that depends on there being enough sources of detectable gravitational waves out there that can be picked up on the ground. Astrophysical models put the expected annual "event rate" anywhere between less than one and more than 200. To guarantee a detection, says Hough, we need to go into space. The European Space Agency's Evolved Laser Interferometer Space Antenna (eLISA) should do just that. Planned to fly in the mid-2030s, its three detectors will form a triangle with sides a million kilometres long. LISA Pathfinder,

a probe to test the technology, is due to launch next month.

eLISA should be swamped with signals from even the weakest sources, and will be the make-or-break test. "We would need to wait for eLISA not seeing gravitational waves from well-defined binary systems before we could be definitive about general relativity being wrong," says Hough.

The prize from a sighting would not just be further confirmation of Einstein's theory, but a new type of astronomy that uses gravitational waves to peer much further back into the universe's history than is possible with light – right to the big bang, perhaps. That would also allow us to witness the birth of

black holes and other processes where a much-sought quantum theory of gravity would otherwise be needed to make sense of things. In anticipation of the space-time fog lifting, Hough and his collaborators are already planning upgrades to existing interferometers and new generations of instruments.

If we don't see anything, the consequences are huge, and not just for general relativity. Gravitational waves are actually a subtle consequence of the special theory of relativity derived by Einstein in 1905, where they serve to prevent gravitational influences propagating across space-time instantaneously. Special relativity's precepts have also been incorporated into other queries, such as the quantum field theories that describe the other forces of nature. "If we fail to discover gravitational waves from a source which we know for sure is within our horizon, then that would be a massive blow to not just general relativity, but many of its alternatives," says Sathyaprakash. ■

"With gravitational waves we could peer back, maybe even to the big bang"

Matthew Chalmers is a freelance writer based in Bristol, UK

SAVE OUR SOILS

A photograph of a dry, brown, plowed field. In the foreground, a barbed-wire fence runs diagonally across the frame, supported by weathered wooden posts. The soil appears dry and cracked. The background is a hazy, yellowish sky, suggesting a dusty or overexposed environment.

Is there hope for our planet's most precious endangered species? Joshua Howgego investigates

FIND the places where farms give way to the California wilderness and you're sure to encounter an endangered species. It is not aggressive, but it is omnivorous, devouring anything that happens to fall dead within its reach. And like most rare beasts, the extinction of Abruptic durixeralfs would have cascading impacts on the ecosystem around it.

Don't be misled by the name. This is neither animal nor plant nor microbe, but a subgroup of soils. Its members nonetheless slot into a classification system every bit as elaborate as that we use to categorise life forms. In the US alone, more than 20,000 soils have been catalogued. Many are facing extinction.

It may seem like madness to speak of soils going extinct, but more than a third of the world's top layer is endangered, according to the UN, which declared 2015 the International Year of Soils. This December, it will release a much-anticipated report on the state of the world's dirt. The news won't be good: we are losing soil at a rate of 30 soccer fields a minute. If we don't slow the decline, all farmable soil could be gone in 60 years. Given soil grows 95 per cent of our food, and sustains human life in other more surprising ways, that is a huge problem. "Many would argue soil degradation is the most critical environmental threat to humans," says Peter Groffman, who studies soil microbes at the Cary Institute of Ecosystem Studies in Millbrook, New York. Yet all is not – quite – lost.

The degradation of the world's dirt has been a disaster in slow motion. "Soil scientists have been prattling on about this for decades," says Groffman. All the while, our understanding of just how crucial soil is has only grown. A single gram might contain 100 million bacteria, 10 million viruses, 1000 fungi, and other populations living amid decomposing plants

and various rocks and minerals.

That means soils not just grow our food, but have been the source of nearly all of our existing antibiotics, and could be our best hope in the fight against antibiotic-resistant bacteria. Well-conditioned soil certainly seems to have ways to keep out dangerous elements. In 2011, a series of experiments at the University of Groningen in the Netherlands suggested that soil types with more diverse communities of microbes fare better at suppressing one strain of *E. coli*. This strain causes particularly violent diarrhoea and even kidney failure in humans, and the soil's action could potentially prevent it entering the food chain. "There's a clear link between soil microbial diversity, plant health and human health," says Rick Ostfeld, who works with Groffman at the Cary Institute.

Soil is also a surprising ally against climate change: as nematodes and microorganisms within soil digest dead animals and plants, they lock in their carbon content. Even in their degraded state, it is estimated the world's soils hold three times the amount of carbon as does the entire atmosphere. Water storage is another talent lost when soils degrade. A UK government report published in 2012 suggested soil degradation costs the country £233 million in flood damage each year.

Small wonder endangered soil is making ecologists so nervous. It's not that the dirt is wiped off the face of the planet. "When folks refer to the soil as endangered, they're not thinking of it in the same sense as endangered species," says Ostfeld. Rather, extinction transforms a fecund soil into a dusty, microbiologically flat shadow of its former self. Once that diversity is gone, it's gone for a while. "Soil takes thousands of years at a minimum to gestate," says Groffman.

Abruptic durixeralfs's problem is that it is of

little direct use for farming owing to its tendency to form a hardpan – a dense, compacted layer that repels both roots and water. But it likes to nestle between swathes of prime agricultural land in its habitats in the western US. Frustrated farmers have resorted to using explosives to blow it out of the way: a dramatic method of soil extinction, but only one of many. "Everything we do causes soil to erode," says Groffman.

A load of manure

Agriculture is by far and away soil's biggest problem. In the wild, nutrients removed by plants are returned to the soil when they die and decay to form rich humus. Humans tend not to return unused parts of harvested crops to replenish those nutrients.

We realised this long ago and developed strategies to get around the problem. We left fields fallow, or rotated crops that required different nutrients, thereby keeping the soil in balance. Growing peas and beans can even add nitrogen, a vital nutrient, to the ground: nodules in their roots host rhizobia bacteria, which grab atmospheric nitrogen and convert it into nitrates.

But these practices became inconvenient as populations grew and agriculture was mechanised. A solution came in the early 20th century with the Haber-Bosch process for manufacturing ammonium nitrate. Farmers have been plying their fields with this synthetic fertiliser ever since.

But over the past few decades, it has become clear this wasn't such a bright idea. Chemical fertilisers can release polluting nitrous oxide into the atmosphere and excess is often washed away with the next rain. This leaches nitrogen into rivers, damaging algal blooms. ➤

Long-term use of fertilisers risks turning even fertile soil to desert

More recently, we have found that indiscriminate fertiliser use hurts the soil itself, turning it acidic and salty. It also suppresses symbiotic relationships between fungi and plant roots, and can even turn beneficial bacteria against each other.

In many ways, fertilisers speed the soil they are supposed to nourish toward extinction. "They really work to grow plants," says Groffman. "So they very effectively hide the nature and extent of soil degradation. As the soil degrades, you just put on more fertiliser."

What's to do? One possible solution is being pursued by Carlos Monreal of Carleton University in Ottawa, Canada, and his colleagues. Inspired by the way plants coexist with soil bacteria, he is on a mission to make fertilisers smarter.

Monreal wants to exploit the way plants signal to bacteria by releasing chemicals. "The plant tells the microbes, 'hey guys, I need nitrogen!'" he says. The microbes then begin working to free nitrogen from organic matter, and the plant soaks it up. In 2011, after nearly a decade of sifting through hundreds of chemicals in soil samples taken from fields of wheat and canola (oilseed rape), Monreal's team identified five compounds that spike just as the plants take in ammonia – these are the chemical signals plants exude to ask for nitrogen.

Monreal then teamed up with Maria DeRosa, also at Carleton, to try to build a fertiliser that keeps its payload locked up until it encounters a plant's signalling compounds.

HOW TO ORGANISE THE EARTH

Just as living things are sorted into orders, genera and species, so soil has its own categorisation systems. The US Department of Agriculture, for example, breaks it down into orders, suborders, great groups, subgroups, families and finally series – the equivalent of a species. The classification criteria are based both on physical characteristics and more subtle factors. The parent material the soil is made from, the microbes living within it, the topography of the land, the climate and the soil's age are all important.

Characterising soils has flagged a few in danger. In 2003 for instance, researchers found that almost 5 per cent of US soils were in danger of serious damage or extinction caused by agriculture or construction, although that may well be an underestimate. A different group scoured soil survey results in China, and found 17 types had gone extinct, and a further 88 were endangered.



PETE MCBRIDE/NATIONAL GEOGRAPHIC/CREATIVE

DeRosa turned to aptamers, short strands of DNA that bind to specific chemicals, much the way antibodies do. After training them to recognise the five compounds, she used the aptamers as scaffolding around a tiny parcel of fertiliser. In the presence of one of the plant signalling compounds, the aptamers would bind to it, rupturing the scaffolding and releasing its contents.

The pair now have a working product, fertiliser-filled capsules that open up in response to the appetite wheat and canola have for nitrogen. Monreal thinks the same process will work with other crops and soil microbes too – although the precise details are under wraps while they try to commercialise the technology. First, it must undergo greenhouse trials, scheduled for spring 2016, and pass other tests to make sure it biodegrades after a few years in the soil. Several groups are working on similar approaches to reduce the environmental impact of fertilisers and even pesticides.

Another school of thought says that any synthetic fertiliser, even in small doses, is bound ultimately to degrade the soil. Such concerns might be addressed by an alternative approach, which replaces synthetic fertilisers and chemical pesticides with the soil's own microbiome.

This research is in its early days, and Pius Floris is one of the people at its vanguard. Floris, who started out running a tree-care business in the Netherlands, now advises some of the world's top soil scientists. He came to realise that the best way to ensure his trees flourished was to take very particular care of the soil, and has developed what he calls a "universal recipe" of beneficial bacteria, mycorrhizal fungi and humus that adheres to

plant roots and helps them extract nutrients.

Under the auspices of a European Union-funded pilot project to resuscitate degraded soils, Floris recently teamed up with researchers at the University of Valladolid in Spain to test this cocktail on local soils whose ability to grow plants had been destroyed by years of fertiliser and pesticide overuse. When the team applied Floris's mix to the desert-like test plots, they began to sprout oats and leguminous plants called vetches. The few plants that grew in the control plots, dosed with traditional pesticides and fertilisers, were small and stunted; those treated with Floris' cocktail were not just healthy at the surface, but their roots had grown strong and long enough to pierce dirt as hard as rock.

Dish the dirt

The promise of these microbial interventions is such that agrochemical companies are taking notice. Microbe-based fertilisers are being developed by chemical giants such as Dupont as well as small start-ups. Several countries, including India, have programmes to foster their use by farmers.

Innovative as they are, these measures will at best make a dent in the global soil degradation problem. "There are some problems you can't invent your way out of," says soil hydrologist Dara Entekhabi at the Massachusetts Institute of Technology. Soil degradation is a complex issue with tendrils poking into areas like climate change, biodiversity, food security and water (see map, right). Better fertilisers won't stop the drought that is ruining soils in California, or avert bulldozers paving over them in rapidly-urbanising China.

"Knowing what soils are where is only a first step to action"



PHOTOGENIC/AGENCIAS GRÁFICAS

To assess our options on a global scale we first need an accurate picture of what soils are out there, and which are endangered. That's not easy. For one thing, it still requires extensive fieldwork; for another, there is no agreed international system for classifying soil (see "How to organise the earth", left).

In an attempt to unify all the different approaches, in 2010 the UN created the Global Soil Map project. Researchers from nine countries are working together to create a real-time, digital repository of the condition of soils worldwide. Right now, the state of the

art is a map with a resolution of 1 kilometre, linked to an online database that can be fed measurements – field surveys, drone surveys, satellite imagery, lab analyses and so on – at any resolution. Cross-referenced with existing data, it provides real-time predictions of soil health: its clay, silt and organic carbon levels, together with acidity and overall density. By 2019, researchers aim to have mapped soils worldwide down to 100 metres, with the results freely accessible to all.

But sophisticated new ways to classify and map soils is only a first step. Action will

Pius Floris hopes to use soils' own microbes to maintain their fertility

require ways of presenting the problem that bring it home to governments and the wider public, says Pamela Chasek at the International Institute for Sustainable Development, a think tank headquartered in Winnipeg, Canada. "Most scientists don't speak language that policy-makers can understand, and vice versa." Chasek and her colleagues have proposed a goal of "zero net land degradation". Like the idea of carbon neutrality, it is an easily understood target that can help shape expectations and encourage action. It would also offer a banner under which projects like Montreal's and Floris' can rally.

For soils on the brink, that may be too late. Several researchers are agitating for the creation of protected zones for endangered soils, although there has been little official movement on the issue so far. One problem is defining what these areas should conserve: areas where the greatest soil diversity is present? Or areas of pristine soils that could act as a future benchmark of quality?

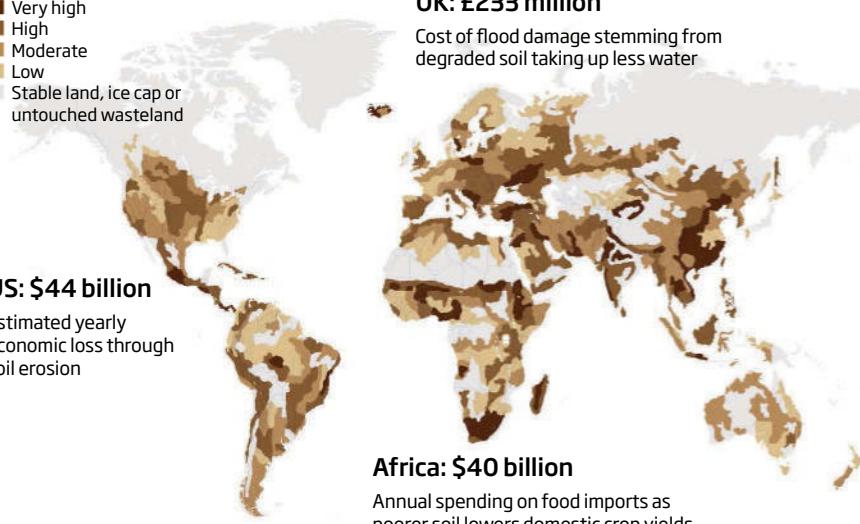
The US has made an effort to at least recognise the importance of soils, by having every state designate a "state soil". California's is the San Joaquin – which, ironically, is an informal name for a soil that belongs to the group frequently in local farmers' crosshairs: Abruptic durixeralfs. When law-makers made it the state soil in 1997, they didn't accompany the honour with any legal protection. That's telling. If we do want to save our soils, we might want to stop treating them like dirt. ■

Earth in crisis

Each year, the world loses an area of healthy soil the size of Louisiana, with major economic consequences

Extent of human-induced soil degradation

- Very high
- High
- Moderate
- Low
- Stable land, ice cap or untouched wasteland



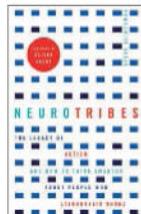
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Joshua Howgego is a feature editor at *New Scientist*

Potentials, not problems

Autism is not a biological flaw, it's a key to our neurodiversity, says **Helen Thomson**

NeuroTribes: The legacy of autism and how to think smarter about people who think differently by Steve Silberman, Allen & Unwin, £16.99



THE "Wizard of Clapham Common" tinkers with copper conductors and wire rods, a socially awkward student creates the first amateur radio transmitter, a young boy solves logic problems in his head, but when tested formally jumps down from his desk and slaps the examiner.

The characters Steve Silberman introduces us to in *NeuroTribes* are complicated, to say the least. But through their complex minds and behaviours, he carefully peels back the layers of medical history that have radically altered the diagnosis of autism and argues that widespread misconceptions about the condition are preventing our culture from reaching its full potential.

It doesn't always make for a comfortable read. Silberman writes how scientists have long searched for a "cure" for autism. How, for example, in just a few sessions, two autistic boys, Mike and Marty, learned how to show affection, jumping into their examiners' arms. That was, of course, to avoid painful electric shocks from the packs affixed to their buttocks and activated if they failed to show said affection.

Silberman gives a particularly moving account of Hans Asperger, one of the first clinicians to define aspects of the autism spectrum. Asperger cleverly presented a handful of high-functioning autistic children to his peers in



ALLAN GRANT/THE LIFE IMAGES COLLECTION/GETTY

Nazi-controlled Vienna. His "little professors", as he called his young patients, had special gifts, he said, that were inextricable from their impairments and would end up benefiting society as a whole.

By focusing on the positives and hiding the negatives,

Hans Asperger prevented the sterilisation of autistic children by those looking to extinguish 'weak' genes

Asperger prevented their forced sterilisation by those looking to extinguish society's "weak" genes. He also gave the impression that autism was a rare condition associated with young genius, while revealing in papers translated decades later that he knew this was far from the truth.

Meanwhile, US psychiatrist Leo

Kanner was simultaneously defining the condition as one that affected only young children, and was caused by cold-hearted "refrigerator parents". This notion was widely received and much to blame for the long history of stigma and shame that became firmly attached to the condition.

Silberman uses the two men to make a provocative argument: had we not used Kanner's "thin" definition of autism for so long, the autism "epidemic" that began when the definition was widened in the 1980s would not have occurred, and we would not have spent so much energy looking for environmental causes or pointing the finger at blameless parents.

Instead, we might have realised much earlier that autism is not a single entity, but a cluster of conditions. For most of the 20th

Some people still believe they can find a "cure" for autism

century, Silberman writes, these conditions were hidden behind competing labels such as "feeble-minded", "multiple personality", or "childhood schizophrenia". What's clear now is that the rising numbers of diagnoses are not caused by some risk factor hidden in our modern world, but are what he calls "a strange gift from our deep past, passed down through millions of years of evolution". Rather than viewing this gift as an error of nature, "a puzzle to be solved and eliminated", it should be seen as incredibly valuable.

Although dispassionate at times, Silberman's sweeping history is always sensitive and builds a persuasive argument that the ability to think differently is

useful, necessary even, for the success of the modern world.

Early on, I was concerned that Silberman underplayed the controversial nature of some of the history, such as supposed links between vaccination and autism. It was only later that he weighed in, firmly emphasising the debunking of such research and the “insidious effect” it has had on society.

His cast of characters is so large, each with a long backstory, that the book can be a slow read; it could do with fewer chapters. And Silberman rarely covers autism’s most disabling aspects. That said, his tales neatly underline how our understanding of autism has been influenced as strongly by a single thinker as by a whole regime.

Where his account of autism’s complex history really shines is in the last third of the book, where we gain an insight into current issues from autistic people themselves. We are left admonished by Ari Ne’eman, an autism-rights activist appointed to the US National Council on Disability by President Barack Obama. Ne’eman says that while the core features of autism can be disabling, many of the difficulties are not to do with the symptoms of autism but with how society treats people who don’t meet expectations of “normal”.

The book gains momentum as we turn a page in history where we see autistic adults begin to rise up and form “tribes” after years of alienation. This growing alliance of autistic individuals, their parents and researchers, all of whom have embraced the concept of neurodiversity, proposes that autism be regarded as a valuable part of humanity’s genetic legacy and that society needs to accept and adapt to people who think differently. Only then, Silberman says, will we allow people to embrace their uniqueness and let society reach its dynamic potential. ■

Helen Thomson is a writer based in London

Peculiar patterns

Can using the arts as a diagnostic tool tell us about ourselves?

Strange Tools: Art and human nature
by Alva Noë, Hill and Wang, \$28

Anil Ananthaswamy



“WHAT is art? Why does it matter to us?” These questions are posed time and again in Alva Noë’s latest book, *Strange Tools*. To Noë, a philosopher at the University of California, Berkeley, ordinary tools are technological things: we make them to organise our lives. But “strange” tools are those that help us make sense of how we organise our lives. For him, “a work of art is a strange tool”.

According to Noë, our lives are governed by organised activities, from walking to dancing, talking to breastfeeding. Such activities, he says, have distinct features: they are primitive, basic and natural, yet demand complex cognitive

Choreography lays bare the impulses that make us dance

and attentional skills; they unfold over time; they serve a purpose, and can be pleasurable. “Our lives are one big complex nesting of organised activities at different levels and scales,” he writes.

More often than not, Noë says, we are unwitting participants in these activities: it’s our “natural, indeed our biological, condition”.

Not surprisingly, given this view point, he sees our lives as a source of existential angst. Why do we do what we do? Why are we the way we are? Art, says Noë, is a way of “illuminating the ways we find ourselves organised”.

He uses dancing to illustrate his point. For Noë, dancing is as natural as suckling. Dances are organised activities, he says. “We participate in them. We get caught up in them. Dancing happens.” Choreography, says Noë, lays bare the impulses that make us dance – it shows how dancing affects our lives. In that sense, choreography is art. Noë likens it to philosophy, which he calls the “choreography of

ideas and concepts and beliefs”. Both “expose the concealed ways we are organised by the things we do”.

Noë’s arguments at times seem obvious, but he has striking insights, for example, when he compares art to map-making: “The task of generating a representation of the lay of the land has its source in a real need, or a felt anxiety.”

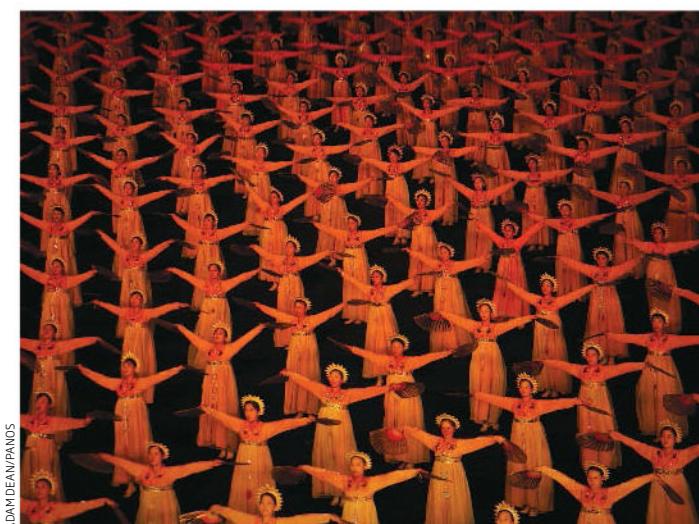
Having set up art as an activity that seeks to expose the patterns that govern us, *Strange Tools* takes

“Our lives are one big complex nesting of organised activities at different levels and scales”

on other ways of looking at art. For instance, whether the emergence of art is an evolutionary adaptation that increases our chances of survival, or whether we can explain art with neuroscience.

You can’t help feeling that Noë wants to elevate art to something that cannot be reduced to neural correlates in the brain, or seen as a consequence of evolution. For him, art “affords revelation, transformation, reorganisation”; it is a subversive activity, not a phenomenon to be explained.

Oddly, *Strange Tools* tries to do just that, and it seems repetitive, as Noë makes the same points many times. Some might object to his view of art as an activity that must make us ask: “What is this? What is this for?”, thus revealing something about ourselves. This is an intriguing, provocative book, but does art always have to be so laden with meaning? ■



ADAM DEAN/PANOS

Anil Ananthaswamy is a consultant for *New Scientist*

Dodging extinction's bullet

Some animals survived an ancient climate catastrophe – **Matthew Cobb** wonders how

The Worst of Times: How life on Earth survived eighty million years of extinctions by Paul B. Wignall, Princeton University Press, \$27.95/£19.95



LIFE on Earth was nearly extinguished 251 million years ago. Some 96 per cent of marine species went extinct.

The world's forests disappeared, and for about a million years no plant grew higher than a half a metre. It took 100 million years for biodiversity to return to pre-extinction levels. The global ecosystem was shattered and the history of our planet took an abrupt turn, laying the basis for the rise of dinosaurs, mammals and flowering plants.

The cause of this catastrophe was a series of immense volcanic eruptions that produced the vast stepped layers of igneous rock known as the Siberian traps (the word “trap” comes from the Dutch for “stair”). This period of hellish volcanic activity spewed hundreds of thousands of gigatonnes of carbon dioxide and other greenhouse gases into the atmosphere, and covered huge areas of land with thousands of cubic kilometres of lava.

In the aptly titled *The Worst of Times*, Paul Wignall, professor of palaeoenvironments at the University of Leeds, explores the cataclysm that precipitated the end-Permian mass extinction. His analysis covers a staggering 80 million years, from the Triassic to the beginning of the Jurassic. He believes that a series of lesser

extinction events in that period had similar volcanic causes.

The book's central claim – unaccountably left until the closing pages – is that the ecological effects of the eruptions were exacerbated because, during this period, the world's entire land mass had fused into a single supercontinent called Pangaea. This had consequences for the environment – for example, a single continent would have led to less rainfall per unit area, which may have meant that some parts were uninhabitable.

In a relaxed style, Wignall describes the significance of recent measurements and discoveries, and introduces us to frambooids, rudists, crurotarsans, gorgonopsians and many other obscure scientific terms. There are no illustrations here, so have Google to hand as you read.

Wignall's excellent introduction to the latest thinking about this key period in Earth's history could profitably be read alongside

Michael Benton's end-Permian-focused *When Life Nearly Died*, recently released in a new edition.

The Worst of Times reveals how little we understand about past ecologies. It is baffling that some taxa, including two major animal groups – fish and insects – breezed through the catastrophe without too much damage.

The profound atmospheric and temperature changes at this time would have led to acidified and

'Either we don't understand extinction, or we don't understand Permian-Triassic ecology. Or both'

oxygen-depleted seas – yet fish, at the top of the food web, survived. Many plants died – but plant-eating and detritus-feeding insects were largely unaffected.

There is something amiss here: either we do not have an accurate picture of the extinction process, or we do not understand Permian-Triassic ecology. Or both.

Wignall's assessment of the environmental consequences of Pangaea and its millions of years of massive volcanic eruptions is uncontroversial. But there are other possibilities he doesn't explore.

When populations of a species are geographically separated, there is eventually an increase in diversity. Perhaps terrestrial life on Pangaea was not particularly diverse, and this made life more vulnerable to the effects of large-scale volcanism. Similar effects may have been felt in the sea. While Pangaea existed, there would, after all, have been relatively few coastline habitats.

Wignall's book is enthralling. But in the end, extinction events are measured through their effects on ecology, not geology. To understand Earth's history – and its future – we must learn far more about how life's web works. ■

Matthew Cobb is a professor of zoology at the University of Manchester, UK



Catastrophic eruptions cleared the way for flowers, dinosaurs and us

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Research Assistant Professor

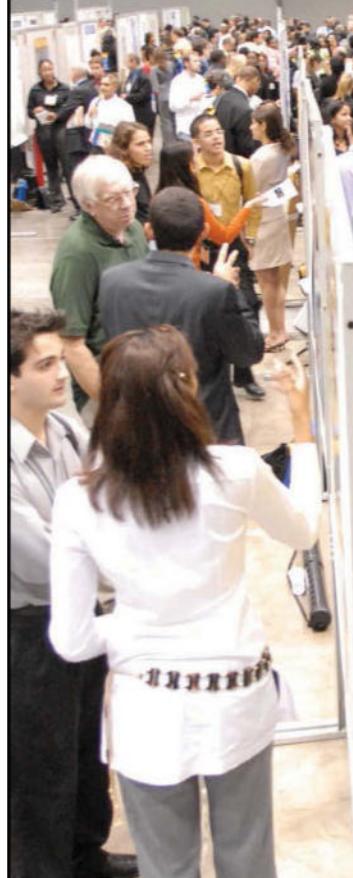
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Structural Biology Assistant Professor

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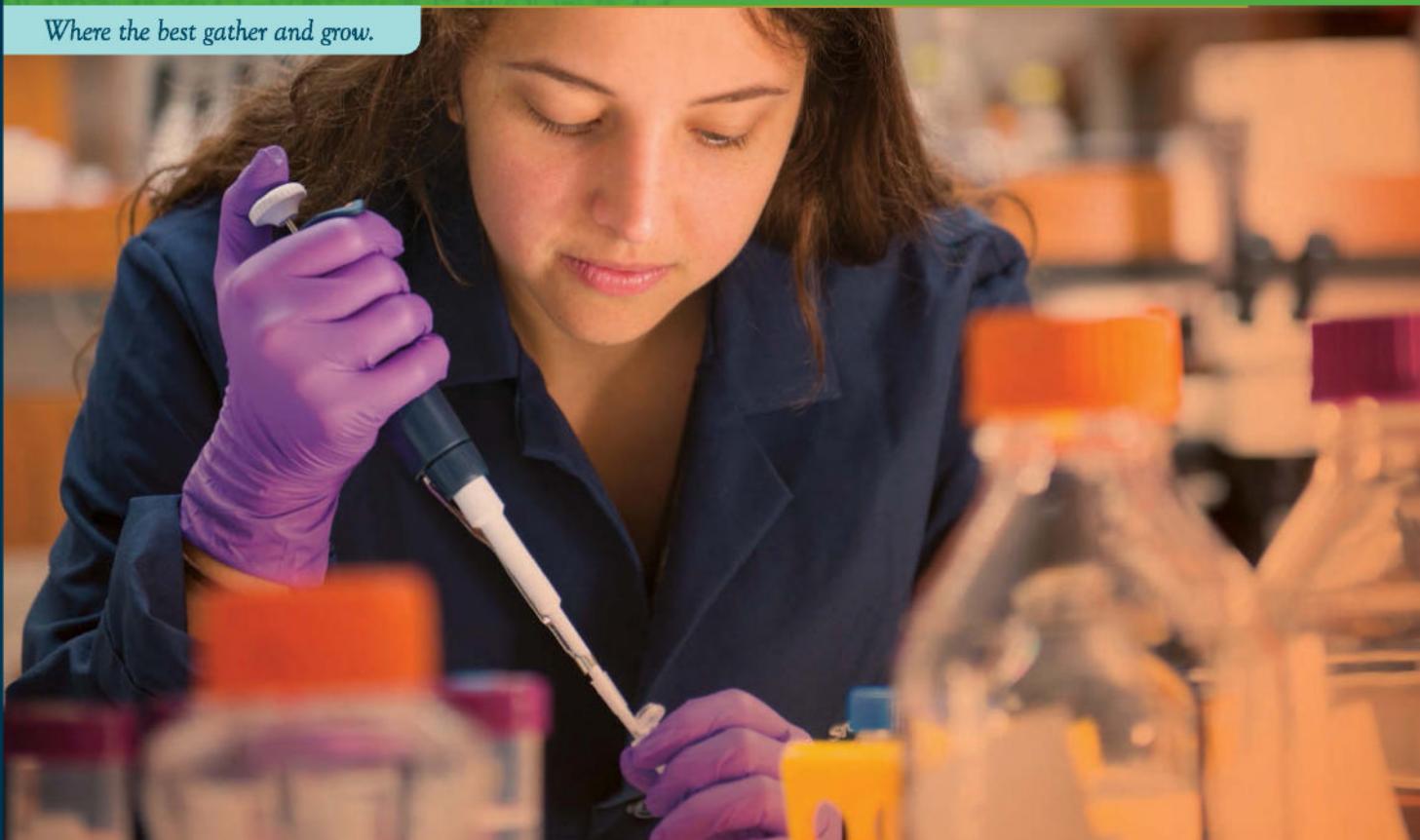
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EDITOR'S PICK



Artificial arbiters will never work

From Emma Fox Wilson

Ariel Procaccia's proposal that artificial intelligences should help resolve disputes (22 August, p 27) is one of the scariest things I have ever read. He wants to base this on economics, on the grounds that "a lot of work has been done on how to formalise, in mathematical terms, what fairness means" and to "design algorithms that can provably achieve those notions of fairness".

It scares me that someone can think this many very silly things at the same time. He thinks it desirable and feasible that computers settle human disputes over issues involving the complex mysteries of the human heart and soul. He thinks that we should do this using - of all godforsaken ideas - the theories that underlie economics. He clearly hasn't looked out of his window recently. Does it look as if the pseudoscience of economics has produced a world that is fair?

Finally, he thinks that a definition of fairness so maimed and truncated that a computer can process it is the best one to choose. This is what happens when education becomes too narrow. Procaccia ought to take a wider view that values history, philosophy and literature. Note what happens when you try to apply the rigorously "fair", from Solomon's "cut the baby in half" judgement to Portia's ruling to take a pound of flesh but no blood.

Birmingham, UK

Consciousness, illusion and agency

From Andy Howe

When I pondered mathematical problems in my youth, my brain would sometimes take me on a ride, rushing me through the final stages to a solution. I would then have to backtrack consciously to check it through.

With rose-tinted spectacles, I remember this only leading me to correct solutions, but there probably were misfires, too. I guess my non-conscious mind took over, as Peter Halligan and David Oakley suggest it does (15 August, p 26).

This strikes me as an interactive process between one's "minds", rather than the conscious mind being, as they postulated, an evolved social contrivance which doesn't have much to do with decision-making processes.

This internal interaction seems to me to be highly advantageous, whether for social skills or for individual action.

Sheffield, UK

From Pushkar Piggott

I was particularly struck by how Halligan and Oakley's ideas fit with the concept of responsibility. The conscious self is not in direct control of every little action yet, socially, it is held responsible for those actions.

Compare this with the notion of responsibility in government. Ministers are held responsible for the actions of their ministry. Since ignorance is no defence, they will make sure they know what is going on, as a matter of self-preservation. By arguing that consciousness exists for sociality, Halligan and Oakley are implying that responsibility is an evolutionary invention.

Cygnets, Tasmania, Australia

From Ray Thompson

I'm reminded of Graham Lawton's observation that humans tend to seek "agents" with purpose

(4 April, p 28). There is a survival advantage in always being on the lookout for the causes of things that happen around you. Could consciousness be a constructed "agent" explaining one's own unconscious actions as things that occur in one's local environment? This construct would provide a valuable interface with other local conscious "constructs" (that is, people), and allow the establishment of social groups. Lymington, Hampshire, UK

From Frank Siegrist

Anthony Castaldo takes issue with the idea that consciousness should be linked to language (Letter, 12 September). He brings up the example of his dog consciously reasoning that it should "ask" to be let out (to avoid making a mess on the carpet and angering its master, I suppose).

I agree that dogs surely possess consciousness. But here the dog is actually communicating, albeit non-verbally. It remains an open question for me whether only social animals like dogs and humans benefit from being conscious. Are naturally lonesome creatures like frogs and turtles conscious too? Maybe consciousness is really just a side effect of communication, even if it appeared long before our species and our verbal language. Granby, Quebec, Canada

Invasion of the killer squid

From Gerald Legg

I was intrigued to read Michael Tennesen's report on Humboldt squid (12 September, p 32). What must be a fear is their potential spread from the Eastern Pacific into the Caribbean Sea and the Atlantic and Indian oceans.

One voracious predator that is already having a powerful influence on coastal marine ecosystems is the lionfish *Pterois*

volitans from the Western Pacific. It has spread to the West Atlantic and the Caribbean, where reef fish have not evolved to deal with this predator, with disastrous results. Hurstpierpoint, West Sussex, UK

A sequel to the great land grab

From Richard Vandewetering

Martin Pratt correctly praises the non-violent process used to divide up the Arctic seabed (29 August, p 24). His nonchalance about the fact that what was once "unowned" will now be split between three already wealthy states is, however, a bit distressing.

Few people recognise that the process of dividing up the seas over the past 40 years has been the largest grab of territory and resources since the Berlin Conference (1884-5) divided Africa between European empires. Could Pratt remind us of the benefits of this process for the majority of humanity, especially the poorest? London, Ontario, Canada

The universe has freedom, if not will

From Nathaniel Hellerstein

John Clark asked for a definition of free will (Letter, 5 September). Here are three: self-control, self-determination, self-causation.

Freedom, being self-caused, is neither random (uncaused) nor deterministic (externally caused). Since causal loops pervade all living processes, it follows that all life possesses free will, to at least some extent. And if everything in the universe has causes in the universe, then it too possesses freedom, though perhaps not will. San Francisco, California, US

From Anthony Castaldo

I agree with Clark that the known laws of physics seem to rule out free will, but I disagree with his

f "What is needed is the maximum number of people participating in an economy, driving growth"

Michael Knight tries to inject some economic reality into Facebook responses to a "living wage" (3 October, p 28)

implication that they are definitive. The issue in which his letter appears has "10 questions physicists can't answer" on the cover. I would add that physicists cannot explain dark matter, dark energy and, even with the Higgs, 98 per cent of mass. Nor can they reconcile gravity with quantum mechanics. I could go on.

Free will would require the future to be non-deterministic and non-random, open to our choices. It would mean our observation of that being true is not an illusion. I don't know what model of physics might support that, but until we have a coherent theory of everything that really does explain everything, I can rest easy because the known laws of physics are clearly not all there is to know, and will undoubtedly be subject to revision.

A hundred-odd years ago, with no knowledge of nuclear fusion, we could not reconcile the apparent ages of Earth and the sun. A hundred-odd years from now, free will might fit quite comfortably within the revised laws of physics. In the meantime, the evidence of my own eyes will

take priority over any theory with a dozen holes in it.
San Antonio, Texas, US

Here's one that I invented earlier

From Brian Oswald

Paul Marks's article on "Eureka machines" (29 August, p 32) that can produce inventions was very interesting, but I was surprised to see no mention of the theory of inventive problem-solving, also known as TRIZ. This was originally based on analysis of Russian patent literature, deriving 40 principles allowing a problem formulated in one technical discipline to be assessed against solutions from others – often with surprisingly useful results.

Wickham, Hampshire, UK

From Alan Wells

Working as a patent professional, I likely dealt with algorithmically generated inventions, mainly in the field of pharmaceuticals. But the art of patent examination involves judgement not just on

the objective problem but also on the nature of a person of "ordinary skill" to whom the claimed innovation would be non-obvious. I assume case law will evolve to accept that this could involve an artificial intelligence.

As Greg Ahahorian says in your article, patent examiners can use the same algorithmic tools as inventors do. So judging the "obviousness" of an invention might turn into a button-pushing contest between the two sides.

There are also inventions whose originality lies in the elucidation of the problem itself. These seem less amenable to automation at present, even if trawling web forums and blogs might be a productive way of harvesting human output.

Chichester, West Sussex, UK

I hope, too, that surviving DNA fragments may yield data on lineages. I wonder whether the fossils may be of more than one hominin species, with cross-breeding – as seems to have happened between Neanderthals and our other ancestors. Could hominin evolution have been powered in part by hybrid vigour? If so our genealogy may come to resemble a network more than a tree – creating yet more headaches for palaeontologists.

Roade, Northamptonshire, UK

Enough with the godswollop

From Connaire Kensit

Bryn Glover (Letter, 5 September), like Alan Webb (4 April), trots out that old Aunt Sally: the atheist whose "axiom that there is no god" is based on faith, not evidence. Redefining the word "atheist" to mean nothing but this mythical beast, rather than real godless folk like me and my parents and grandparents, allowed Webb to claim that "being an atheist is just as irrational as being a theist". Glover similarly, invents "anti-theists... as irrational as... current theists".

I suspect that Glover and Webb quite unaxiomatically disbelieve in Inari, the Japanese fox-headed god of agriculture, despite his many worshippers, in just the same way as we godless heathen disbelieve in the One God of Christians, Muslims etc. Atheism is a faith in the same way that not-playing-tennis is a sport.

London, UK

Human origins as a dense network

From Steve Blyth

I look forward to the dating of the *Homo naledi* fossils discovered in South Africa (12 September, p 8).

TOM GAULD



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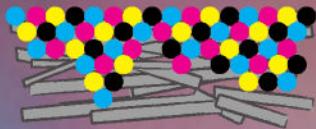
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QUANTUM uncertainty plagues the rivers, canals and harbours of the Netherlands. Henk Rijneveld reports confusion among those working with a government system to monitor ship movements.

The system aims to record details of every vessel that passes through a lock, so that the authorities are prepared in the event of a disaster. A newly drafted document requires Henk to log the number of stowaways, as well as the number of passengers and crew.

However, Henk says, a stowaway is only a stowaway so long as nobody knows he or she is there. Once discovered, a stowaway is recorded as a passenger, or just possibly a crew member. "Just like Schrödinger's cat, the stowaway is gone when we open the place where they have been sitting, but afterwards we have an extra member on the passenger list. So we never fill in the 'stowaways' number," he adds.

All this makes Henk wonder why the authorities have included a box for recording stowaways at all. Perhaps it's another example of

the Heisenberg-like "unfunctionality principle" at work (19 September).

A PROMOTIONAL magazine insert offers Alick Barnett a light with "a 360° wider beam angle than traditional LED bulbs". Alick ponders: "I can't recall seeing LED bulbs with a 0°-wide beam." Feedback thinks that would be a laser, and best not looked into.

PREVIOUSLY, Feedback discussed Athene Donald's claim that girls' science aspirations are harmed by toys fostering passive play, such as "combing the hair of Barbie" (19 September). Giuseppe Sollazzo is reminded of a passage in Linda Grant's novel *When I Lived in Modern Times* on the danger of using perming agents on hair dyed with copper compounds. "People think that hairdressing is a puerile, superficial art," Grant wrote, "but if you don't know your chemistry you're in trouble."

IN RESPONSE to our search for amusing and pithy research paper titles, Tony King harks back to

1965 to offer "Magnetization Ripple and Arctic Foxes".

Published in the *Journal of Applied Physics*, the paper concerns the magnetic properties of thin films, but the reference to Arctic foxes is more mysterious.

"It is recalled that random number sequences appear to have a periodicity of about 3.5 units," say the authors, "a phenomenon now recognized as having led to the assignment of a periodicity in the population of Arctic foxes." Seeing patterns where there are none is a well-documented human pastime; but what is so special about 3.5? If anyone knows, please tell.

CONTINUING the animal theme, John Dobson recalls a 1957 paper by Albert E. Wood on where rabbits ought to be placed in the phylogenetic tree, and in particular whether they share an ancestral bough with rodents or with hooved mammals. The question seems to have so challenged Wood that he appears to have contemplated a third possibility. His treatise was published under the title "What, If Anything, Is a Rabbit?"

THE study of Earth's crust threatens to be a dry endeavour, so thanks to Jeanette Harmann for offering two delicious papers from the field of geology. Discussing the strength of the continental lithosphere, James Jackson asks "Time to abandon the jelly sandwich?" This led two of his colleagues to ponder "Jelly sandwich or crème brûlée?" Did someone say "lunch"?

THE UK government is forging ahead with its proposed blanket ban on psychoactive substances (20 June). Some are concerned that its wording is so expansive that it is not clear what substances it would leave unbanned.

Mike Penning, minister of state for policing and justice, has written to church representatives to allay fears that incense would be prohibited by the legislation, insisting that "we do not believe it right to equate the effect of incense wafting through

the air with the direct inhalation of fumes, for example from a solvent."

Feedback extends its sympathy to the Right Honourable Mike Penning: if the plan really is to ban all psychoactive substances except in stated cases, he has a lot of letters to write. In this instance, altar boys can once more swing those censers with aplomb. We are now diverted by the question of what altar girls, if any, may do.

FURTHER to stories of things that are so stupid they are "beyond wrong" (29 August), Roger Leitch writes with a story he heard as a student. A British Rail employee was collared by a frustrated commuter who told him: "I notice that the carriages at the front of the train are crowded, with standing room only, while those at the back are nearly empty. This seems to happen nearly every day. Why not take the carriages at the back and put them at the front?"

FINALLY, Henry Carpenter writes with a Truly Horrible Idea to Save the Planet. "To offset the effects of global warming, we should lower comets



such as 67P/Churyumov-Gerasimenko on to the surface of Earth," he says. Like titanic ice cubes, this celestial bounty could be used to restore cold ocean currents or top up reservoirs, explains Henry. There's just the small matter of coaxing them down to Earth.

John Davnall writes: "Good to see that Omar Sultan's archaeological team at Mes Aynak includes 'a skeleton crew'" (26 September, p 35)

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Hue goes there?

How far beyond the visible spectrum does a rainbow extend?

■ The visible spectrum runs from about 400 nanometres (violet) to 700 nanometres (far red). The spectrum produced by a rainbow will depend on two factors: absorption by water, mainly in the form of vapour (because light must pass through water droplets

"Infrared rainbows would look intense on Saturn's moon Titan, if you had the right equipment"

to form a rainbow), and the light source, in this case direct sunlight.

Water transmits light best at 400 nanometres. That is why everything looks blue underwater – the longer wavelengths are being absorbed. Water transmits reasonably well in the ultraviolet up to 200 nanometres, so the strength of the violet end of a rainbow depends on the light source.

As it happens, ultraviolet light from the sun is absorbed by the ozone layer and then dispersed in the atmosphere by what's known as Rayleigh scattering. So direct sunlight reaching Earth is relatively low in ultraviolet, with essentially nothing coming through below 300 nanometres. This, then, marks the short end of the rainbow's spectrum.

The infrared end of the rainbow is more to do with fading out. As light's wavelength increases from

700 to 1000 nanometres, the proportion transmitted by water drops by 90 per cent. The available light from the sun is also down to half of its peak at 1000 nanometres, so we can take that as a practical upper limit.

There will be a couple of dips in the spectrum before that, appearing as dim bands in the rainbow. These are the result of absorption by atmospheric oxygen (at 762 nanometres) and water vapour (approximately 900 nanometres).

In practice, this gives us a rainbow spectrum ranging from 300 to 1000 nanometres, although the infrared end will be quite faint.

*Guy Cox
St Albans, New South Wales, Australia*

■ To form, rainbows need light and something transparent to refract it. However, water is only transparent for a narrow sliver of the electromagnetic spectrum, centred on visible light.

On Earth, only a little infrared and ultraviolet light from the sun sneaks through. But infrared rainbows may form on Saturn's moon Titan, where the atmosphere is transparent to these wavelengths.

Titan is too cold for liquid water to form on its surface. Whereas we have a water cycle on Earth, Titan has a methane cycle and, because liquid methane is also transparent, methane rain might give rise to rainbows. They would be slightly bigger than terrestrial

ones, with a primary radius of about 49 degrees instead of 42.5 degrees, and would have a hint of orange from Titan's atmosphere. But they would be hard for our eyes to spot as hazy skies would allow very little visible light to reach the surface.

In contrast, the infrared portion of the rainbow would be intense, although you would need special equipment to see it. The bow would have a radius of a little over 50 degrees.

*Mike Follows
Sutton Coldfield
West Midlands, UK*

■ Although not directly relevant to your question, it's worth examining a little known detail of the atmosphere's effect on light.

We often hear that Rayleigh scattering of light by water vapour makes the sky blue, but the major contributor is actually absorption of light by ozone in the very broad "Chappuis band", centred in the orange.

The colour of the clear sky



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around twilight is dominated by ozone. Without it, the zenith sky would be a greyish straw-yellow, instead of the deep steely blue we see.

*Robert Fosbury
Emeritus astronomer
European Southern Observatory
Garching, Germany*

This week's questions

WASP-PROOF

How do badgers withstand being stung when they raid wasp nests?

*A. Gardener
Haywards Heath, West Sussex, UK*

GENERATION GAP

Are we more closely related to early humans the fewer the generations separating us from them? For example, if all your ancestors tended to have children late in life, would you be closer genetically to early humans than someone whose ancestors had children in their early 20s?

*Laura Stronge
London, UK*

PIECES OF EIGHT

During a school lesson outdoors, we stumbled upon what we think is an eight-headed daisy (left). It's certainly very wide. What could have caused this unusual flower to form?

*Toby Skinner and Jonathon Chappell
Barton Court Grammar School
Canterbury, Kent, UK*

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